PATENT COOPERATION TREATY

PCT

NOTIFICATION OF ELECTION

(PCT Rule 61.2)

To:
Commissioner US Department of Commerce United States Patent and Trademark Office, PCT 2011 South Clark Place Room CP2/5C24 Arlington, VA 22202 ETATS-UNIS D'AMERIQUE in its capacity as elected Office

Date of mailing (day/month/year) 13 November 2000 (13.11.00)

International application No. PCT/SE99/00894	Applicant's or agent's file reference P144PC00/WM
International filing date (day/month/year) 10 June 1999 (10.06.99)	Priority date (day/month/year) 26 March 1999 (26.03.99)

Applicant
GRANLUND, Gösta

1. The designated Office is hereby notified of its election made:

    [X] in the demand filed with the International Preliminary Examining Authority on:

    18 October 2000 (18.10.00)

    [ ] in a notice effecting later election filed with the International Bureau on:

2. The election   [X] was

    [ ] was not

    made before the expiration of 19 months from the priority date or, where Rule 32 applies, within the time limit under Rule 32.2(b).

The International Bureau of WIPO 34, chemin des Colombettes 1211 Geneva 20, Switzerland	Authorized officer Charlotte ENGER
Facsimile No.: (41-22) 740.14.35	Telephone No.: (41-22) 338.83.38

PATENT COOPERATION TREATY

PCT

NOTICE INFORMING THE APPLICANT OF THE COMMUNICATION OF THE INTERNATIONAL APPLICATION TO THE DESIGNATED OFFICES

(PCT Rule 47.1(c), first sentence)

From the INTERNATIONAL BUREAU

To:
MRAZEK, Werner
Aros Patent AB
P.O. Box 1544
S-751 45 Uppsala
SUÈDE

ANKOM

2000 -10- 19

Date of mailing (day/month/year)
05 October 2000 (05.10.00)

Applicant's or agent's file reference	IMPORTANT NOTICE
P144PC00/WM	

International application No.	International filing date (day/month/year)	Priority date (day/month/year)
PCT/SE99/00894	10 June 1999 (10.06.99)	26 March 1999 (26.03.99)

Applicant
GRANLUND, Gösta

1. Notice is hereby given that the International Bureau has communicated, as provided in Article 20, the international application to the following designated Offices on the date indicated above as the date of mailing of this Notice:

   AU,KP,KR,US

   In accordance with Rule 47.1(c), third sentence, those Offices will accept the present Notice as conclusive evidence that the communication of the international application has duly taken place on the date of mailing indicated above and no copy of the international application is required to be furnished by the applicant to the designated Office(s).

2. The following designated Offices have waived the requirement for such a communication at this time:

   AE,AL,AM,AP,AT,AZ,BA,BB,BG,BR,BY,CA,CH,CN,CU,CZ,DE,DK,EA,EE,EP,ES,FI,GB,GD,GE,GH,
   GM,HR,HU,ID,IL,IN,IS,JP,KE,KG,KZ,LC,LK,LR,LS,LT,LU,LV,MD,MG,MK,MN,MW,MX,NO,NZ,OA,
   PL,PT,RO,RU,SD,SE,SG,SI,SK,SL,TJ,TM,TR,TT,UA,UG,UZ,VN,YU,ZA,ZW
   The communication will be made to those Offices only upon their request. Furthermore, those Offices do not require the applicant to furnish a copy of the international application (Rule 49.1(a-bis)).

3. Enclosed with this Notice is a copy of the international application as published by the International Bureau on

   05 October 2000 (05.10.00) under No. WO 00/58914

REMINDER REGARDING CHAPTER II (Article 31(2)(a) and Rule 54.2)

If the applicant wishes to postpone entry into the national phase until 30 months (or later in some Offices) from the priority date, a demand for international preliminary examination must be filed with the competent International Preliminary Examining Authority before the expiration of 19 months from the priority date.

It is the applicant's sole responsibility to monitor the 19-month time limit.

Note that only an applicant who is a national or resident of a PCT Contracting State which is bound by Chapter II has the right to file a demand for international preliminary examination.

REMINDER REGARDING ENTRY INTO THE NATIONAL PHASE (Article 22 or 39(1))

If the applicant wishes to proceed with the international application in the national phase, he must, within 20 months or 30 months, or later in some Offices, perform the acts referred to therein before each designated or elected Office.

For further important information on the time limits and acts to be performed for entering the national phase, see the Annex to Form PCT/IB/301 (Notification of Receipt of Record Copy) and Volume II of the PCT Applicant's Guide.

The International Bureau of WIPO 34, chemin des Colombettes 1211 Geneva 20, Switzerland	Authorized officer J. Zahra
Facsimile No. (41-22) 740.14.35	Telephone No. (41-22) 338.83.38

PATENT COOPERATION TREATY

PCT 526 Rec'd PCT/PTO 15 MAY 2000

INTERNATIONAL SEARCH REPORT

(PCT Article 18 and Rules 43 and 44)

Applicant's or agent's file reference P11235WO	FOR FURTHER ACTION	see Notification of Transmittal of International Search Report (Form PCT/ISA/220) as well as, where applicable, item 5 below.
International application No. PCT/SE 99/01969	International filing date *(day/month/year)* 2 November 1999	(Earliest) Priority Date *(day/month/year)* 30 November 1998

Applicant

Telefonaktiebolaget LM Ericsson (publ)

This international search report has been prepared by this International Searching Authority and is transmitted to the applicant according to Article 18. A copy is being transmitted to the International Bureau.

This international search report consists of a total of ___3___ sheets.

[X] It is also accompanied by a copy of each prior art document cited in this report.

1. [ ] Certain claims were found unsearchable (See Box I).

2. [ ] Unity of invention is lacking (See Box II).

3. [ ] The international application contains disclosure of a nucleotide and/or amino acid sequence listing and the international search was carried out on the basis of the sequence listing

    [ ] filed with the international application.

    [ ] furnished by the applicant separately from the international application,

        [ ] but not accompanied by a statement to the effect that it did not include matter going beyond the disclosure in the international application as filed.

    [ ] transcribed by this Authority.

4. With regard to the title, [X] the text is approved as submitted by the applicant.

    [ ] the text has been established by this Authority to read as follows:

5. With regard to the abstract,

    [X] the text is approved as submitted by the applicant.

    [ ] the text has been established, according to Rule 38.2(b), by this Authority as it appears in Box III. The applicant may, within one month from the date of mailing of this international search report, submit comments to this Authority.

6. The figure of the drawings to be published with the abstract is:

Figure No. ___1___
  [ ] as suggested by the applicant.
  [X] because the applicant failed to suggest a figure.
  [ ] because this figure better characterizes the invention.

  [ ] None of the figures.

Form PCT/ISA/210 (first sheet) (July 1992)

INTERNATIONAL SEARCH REPORT

International application No.

PCT/SE 99/01969

A. CLASSIFICATION OF SUBJECT MATTER

IPC7: H04Q 7/38, H04Q 7/32

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

IPC7: H04Q

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	WO 9841044 A2 (NORTHERN TELECOM INC.), 17 Sept 1998 (17.09.98), page 9, line 28 – page 24, line 5, figures 1,4, claims 1-27	1-5,7-11,19, 22-24,27,28
Y	US 5077790 A (THOMAS V. D'AMICO ET AL), 31 December 1991 (31.12.91), column 1, line 41 – column 2, line 6, figures 4a,4b,5a,5b, claims 1-10	1-5,7-11,19, 22-24,27,28
A	US 5553315 A (ARUN SOBTI ET AL), 3 Sept 1996 (03.09.96), column 2, line 55 – column 4, line 45, figure 3, claims 1-18	1,7,19,24

[X] Further documents are listed in the continuation of Box C.   [X] See patent family annex.

* Special categories of cited documents:
"A" document defining the general state of the art which is not considered to be of particular relevance
"E" erlier document but published on or after the international filing date
"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)
"O" document referring to an oral disclosure, use, exhibition or other means
"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
"X" document of particular relevance: the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
"Y" document of particular relevance: the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art
"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
21 February 2000	10. 03. 2000
Name and mailing address of the ISA/ European Patent Office	Authorized officer
Facsimile No.	Klas Arvidsson/cs Telephone No.

INTERNATIONAL SEARCH REPORT

C (Continuation).   DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US 5722084 A (LEWIS MARK CHAKRIN ET AL), 24 February 1998 (24.02.98), column 1, line 40 - line 55, figures 3,4, claims 1-12 -- --------	1,7,19,24

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
WO 9841044 A2	17/09/98	NONE	
US 5077790 A	31/12/91	AU 649742 B	02/06/94
		NO 930352 A	02/02/93
		AT 173119 T	15/11/98
		AU 8769091 A	17/08/92
		CA 2087841 A,C	01/07/92
		DE 69130458 D	00/00/00
		EP 0565528 A,B	20/10/93
		FI 930307 A	26/01/93
		JP 2546756 B	23/10/96
		JP 6505837 T	30/06/94
		KR 9600935 B	15/01/96
		WO 9212584 A	23/07/92
US 5553315 A	03/09/96	NONE	
US 5722084 A	24/02/98	CN 1101469 A	12/04/95
		EP 0630167 A	21/12/94
		JP 7107187 A	21/04/95
		US 5297192 A	22/03/94
		CA 2045801 A,C	29/03/92
		DE 69124445 D,T	26/06/97
		EP 0478231 A,B	01/04/92
		ES 2096631 T	16/03/97
		JP 2593599 B	26/03/97
		JP 6343108 A	13/12/94
		US 5297191 A	22/03/94
		CA 2045800 A,C	29/03/92
		JP 2801445 B	21/09/98
		JP 6284078 A	07/10/94

PATENT COOPERATION TREATY

PCT

INTERNATIONAL PRELIMINARY EXAMINATION REPORT

(PCT Article 36 and Rule 70)

Applicant's or agent's file reference P144PC00/WM	FOR FURTHER ACTION	See Notification of Transmittal of International Preliminary Examination Report (Form PCT/IPEA/416)
International application No. PCT/SE99/00894	International filing date *(day/month/year)* 10.06.1999	Priority date *(day/month/year)* 26.03.1999

International Patent Classification (IPC) or national classification and IPC7
G 06 T 9/00, G 06 T 7/00, G 06 K 9/00

Applicant
Granlund, Gösta

1. This international preliminary examination report has been prepared by this International Preliminary Examining Authority and is transmitted to the applicant according to Article 36.

2. This REPORT consists of a total of __4__ sheets, including this cover sheet.

   ☐ This report is also accompanied by ANNEXES, i.e., sheets of the description, claims and/or drawings which have been amended and are the basis for this report and/or sheets containing rectifications made before this Authority (see Rule 70.16 and Section 607 of the Administrative Instructions under the PCT).

   These annexes consist of a total of _____ sheets.

3. This report contains indications relating to the following items:

   I ☒ Basis of the report

   II ☐ Priority

   III ☐ Non-establishment of opinion with regard to novelty, inventive step and industrial applicability

   IV ☐ Lack of unity of invention

   V ☒ Reasoned statement under Article 35(2) with regard to novelty, inventive step or industrial applicability; citations and explanations supporting such statement

   VI ☒ Certain documents cited

   VII ☐ Certain defects in the international application

   VIII ☐ Certain observations on the international application

Date of submission of the demand 18.10.2000	Date of completion of this report 18.07.2001
Name and mailing address of the IPEA/SE Patent- och registreringsverket Telex Box 5055 17978 S-102 42 STOCKHOLM PATOREG-S Facsimile No. 08-667 72 88	Authorized officer Patrik Bildefalk/mj Telephone No. 08-782 25 00

Form PCT/IPEA/409 (cover sheet) (January 1998)

INTERNATIONAL PRELIMINARY EXAMINATION REPORT

International application No.

PCT/SE99/00894

I. Basis of the report

1. With regard to the **elements** of the international application:*

   ☒ the international application as originally filed

   ☐ the description:

   pages _____ , as originally filed

   pages _____ , filed with the demand

   pages _____ , filed with the letter of _____

   ☐ the claims:

   pages _____ , as originally filed

   pages _____ , as amended (together with any statement) under article 19

   pages _____ , filed with the demand

   pages _____ , filed with the letter of _____

   ☐ the drawings:

   pages _____ , as originally filed

   pages _____ , filed with the demand

   pages _____ , filed with the letter of _____

   ☐ the sequence listing part of the description:

   pages _____ , as originally filed

   pages _____ , filed with the demand

   pages _____ , filed with the letter of _____

2. With regard to the **language**, all the elements marked above were available or furnished to this Authority in the language in which the international application was filed, unless otherwise indicated under this item.
   These elements were available or furnished to this Authority in the following language _____ which is:

   ☐ the language of a translation furnished for the purposes of international search (under Rule 23.1(b)).

   ☐ the language of publication of the international application (under Rule 48.3(b)).

   ☐ the language of the translation furnished for the purposes of international preliminary examination (under Rules 55.2 and/ or 55.3).

3. With regard to any **nucleotide and/or amino acid sequence** disclosed in the international application, the international preliminary examination was carried out on the basis of the sequence listing:

   ☐ contained in the international application in written form.

   ☐ filed together with the international application in computer readable form.

   ☐ furnished subsequently to this Authority in written form.

   ☐ furnished subsequently to this Authority in computer readable form.

   ☐ The statement that the subsequently furnished written sequence listing does not go beyond the disclosure in the international application as filed has been furnished.

   ☐ The statement that the information recorded in computer readable form is identical to the written sequence listing has been furnished.

4. ☐ The amendments have resulted in the cancellation of:

   ☐ the description, pages _____

   ☐ the claims, Nos. _____

   ☐ the drawings, sheet/fig _____

5. ☐ This report has been established as if (some of) the amendments had not been made, since they have been considered to go beyond the disclosure as filed, as indicated in the Supplemental Box (Rule 70.2 (c)).**

* *Replacement sheets which have been furnished to the receiving Office in response to an invitation under Article 14 are referred to in this report as "originally filed" and are annexed to this report since they do not contain amendments (Rules 70.16 and 70.17).*

** *Any replacement sheet containing such amendments must be referred to under item I and annexed to this report.*

Form PCT/IPEA/409 (Box I) (January 1998)

INTERNATIONAL PRELIMINARY EXAMINATION REPORT

V. **Reasoned statement under Article 35(2) with regard to novelty, inventive step or industrial applicability; citations and explanations supporting such statement**

1. Statement

Novelty (N)	Claims	1-19		YES
	Claims			NO
Inventive step (IS)	Claims	1-19		YES
	Claims			NO
Industrial applicability (IA)	Claims	1-19		YES
	Claims			NO

2. Citations and explanations (Rule 70.7)

The document cited in the International Search Report (US5301019A) represents the prior art. The claimed invention stated in claims 1-19 is not considered to be anticipated by this document. The document does not reveal an artificial vision method and system where a percept vector is transformed into a feature vector subsequently multiplied by a linkage matrix to generate a response array as described by these claims.

According to the arguments stated above, the invention claimed in claims 1-19 is novel, considered to involve an inventive step and have industrial applicability.

INTERNATIONAL PRELIMINARY EXAMINATION REPORT

VI. Certain documents cited

1. Certain published documents (Rule 70.10)

Application No. Patent No.	Publication date *(day/month/year)*	Filing date *(day/month/year)*	Priority date (valid claim) *(day/month/year)*
WO 9930270 A1	17.06.1999	16.11.1998	08.12.1997

2. Non-written disclosures (Rule 70.9)

Kind of non-written disclosure	Date of non-written disclosure *(day/month/year)*	Date of written disclosure referring to non-written disclosure *(day/month/year)*

INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(54) Title: ARTIFICIAL VISION METHOD AND SYSTEM

(57) Abstract

The present invention is an artificial vision method and a system that has a rich structure and allows continuous transitions between different models. The artificial vision system includes means (12, 14) for generating an image percept vector, means (16) for transforming this image percept vector into a feature vector, and means (16) for generating a response vector by multiplying the feature vector by a corresponding trained linkage matrix modeling a percept–response system. The invention overcomes the drawbacks of discrete systems, having a large number of logical states, and of continuous systems, having only a limited complexity.

ARTIFICIAL VISION METHOD AND SYSTEM

TECHNICAL FIELD

5   The present invention relates to an artificial vision method and system. The invention may, for example, be used for control in robotics systems.

BACKGROUND

10   Traditionally artificial vision systems have been either discrete or continuous.

Discrete systems are characterized by a large number of logical states (0 or 1), normally implemented by a computer, which gives a rich structure. This 15 allows for switching of the system between many different states implementing different models. However, a continuous transition between models is often difficult with such a structure, since the discrete switching structure can not easily transfer knowledge about system states and boundary conditions.

20

A continuous system implements classical control strategies. This generally allows only a fairly limited complexity, with a limited number of variables, since the systems otherwise become very unwieldy.

25   SUMMARY

An object of the present invention is an artificial vision method and system that has a rich structure and allows continuous transitions between different models.

30

This object is solved in accordance with the appended claims.

BRIEF DESCRIPTION OF THE DRAWINGS

The invention, together with further objects and advantages thereof, may best be understood by making reference to the following description taken together with the accompanying drawings, in which:

Fig. 1 is a set of diagrams illustrating generation of an image percept vector of a one-dimensional image containing a dot;

Fig. 2 is a set of diagrams illustrating generation of an image percept vector of a one-dimensional image containing another dot;

Fig. 3 is a set of diagrams illustrating generation of an image percept vector of a one-dimensional image containing still another dot;

Fig. 4 is a set of diagrams illustrating generation of an image percept vector of a one-dimensional image containing two dots;

Fig. 5 is a set of diagrams illustrating generation of an image percept vector of a one-dimensional image containing two different dots;

Fig. 6 is a set of diagrams illustrating generation of an image percept vector of a one-dimensional image containing two closely spaced dots;

Fig. 7 is a two-dimensional image containing two dots;

Fig. 8 is a diagram illustrating a detector arrangement for generation of an image percept vector from the image in fig 7;

Fig. 9 is a diagram illustrating the image percept vector generated by the detector arrangement in fig. 8;

Fig. 10 is a diagram of a circle that is shifted along a horizontal line for training purposes;

Fig. 11 is a diagram of a circle that is shifted along a vertical line for training purposes;

Fig. 12 is a diagram of a set of different size circles used for training;

Fig. 13 is a diagram illustrating a detector arrangement for detecting line segments;

Fig. 14 is an embodiment of an artificial vision system in accordance with the present invention; and

Fig. 15 is a flow chart illustrating an embodiment of the method in accordance with the present invention.

DETAILED³ DESCRIPTION

An essential feature of the present invention is an image percept vector. This concept will now be described with reference to fig. 1-9. First the concept will be described in one dimension (fig. 1-6). Then the concept will be generalized to two or more dimensions (fig. 7-9).

Fig. 1 is a set of diagrams illustrating generation of an image percept vector of a one-dimensional image containing a dot. The upper part of fig. 1 includes an image along a line segment from x=0 to x=10 with a single dot at x=7. Thus this image could simply be represented as "x=7", the location of the dot.

Another way of representing the image, called channel representation, is suggested by the manner in which the dot may actually be detected. To detect the dot some kind of detector is used. In order to give any information on the location of the dot, such a detector can not cover the entire image. If this were the case, the detector would only indicate that there is a dot in the image, but not where it is located. Thus, it is natural to use an array of detectors, each covering only a part of the one-dimensional image. Such an array is illustrated by the curves in fig. 1. Each curve represents the transfer function of a local dot detector. In fig. 1 a typical dot detector has the transfer function:

$$p_k(x) = \begin{cases} \cos^2\left(\dfrac{\pi}{3}(x-k)\right) & if \quad k-\dfrac{3}{2} \le x \le k+\dfrac{3}{2} \\ 0 & otherwise \end{cases}$$

With this choice the detectors will have their most sensitive center portions at integer coordinate values x=k. This is of course not necessary. With other choices of scaling factors and offsets in the argument of the raised cosine function, the density and overlap of these detectors may be varied. Furthermore, other choices of transfer functions, such as gaussian transfer functions are also possible.

An essential and required feature of a detector arrangement is that the application of a stimulus activates more than one channel. For a description of point objects, this requires that the transfer functions of the detectors partially overlap. This implies that the single dot at x=7 in fig. 1 will activate several detectors. In fig. 1 the activated detectors have been indicated by thicker solid curves. Only the detectors that have non-zero transfer functions at the location of the dot will be activated and produce a non-zero output signal. This has been indicated by the bar diagram under the array of transfer functions in fig. 1. For a dot at x=7, the detectors at x=6, 7, 8 will be the only activated detectors. The detector at x=7 will give an output signal $p_7=1$, while the other two detectors will give $p_6=p_8=0.25$. As indicated at the bottom of fig. 1, the image (the dot) may be represented as the image percept vector:

$$x = [0 \ 0 \ 0 \ 0 \ 0 \ 0 \ 0 \ 0.25 \ 1.0 \ 0.25 \ 0 \ 0 \ 0]^T$$

where "T" denotes transpose. Typically most of the outputs or vector elements will be zero, i. e. the vector is sparse. While the output of a single channel (detector) would not uniquely define a corresponding scalar value x, the set of outputs from partially overlapping channels will (a method for converting a vector to a scalar will be described below). The reason for the extra two detectors (at x=-1 and x=11) at the ends of the image is the required overlap of the transfer functions.

Fig. 2 is a set of diagrams illustrating generation of an image percept vector of a one-dimensional image containing another dot. This figure illustrates that the number of activated detectors will depend on the location of the dot. In this case the dot is located at x=6.5. Therefore only the detectors at x=6 and x=7 will be activated. However, at least two detectors will always be activated (due to the overlap) irrespective of the location of the dot in the image.

Fig. 3 is a set of diagrams illustrating generation of an image percept vector of a one-dimensional image containing still another dot. This figure illustrates

that the dot may have an arbitrary location (x=6.73 in the example) in the image and still be detected and represented by an image percept vector **x**.

Fig. 4 is a set of diagrams illustrating generation of an image percept vector of a one-dimensional image containing two dots. In this case the image percept vector **x** will include two detector sections with non-zero outputs corresponding to the two dots. Note that the number of dimensions of the percept vector is still the same as in fig. 1-3, although the image now contains two dots.

Fig. 5 is a set of diagrams illustrating generation of an image percept vector of a one-dimensional image containing two different dots. In this case the dots are closer to each other, but they can still be identified as two separate dots.

Fig. 6 is a set of diagrams illustrating generation of an image percept vector of a one-dimensional image containing two closely spaced dots. In this case the detector at x=6 is activated by both dots, and it starts to become difficult to separate the dots. This illustrates the fact that the detector density must be determined by the desired resolution on the image.

Having described the concepts of channel representation and image percept vectors for the one-dimensional case, it is now time to generalize these concepts to more realistic two-dimensional images.

Fig. 7 is a two-dimensional image containing two dots. One is located at x=1, y=9 and the other at x=6.25, y=2.75. As will be illustrated below, this two-dimensional image may also be represented by an image percept vector.

Fig. 8 is a diagram illustrating a detector arrangement for generation of an image percept vector from the image in fig 7. In this case there are two-dimensional detectors having typical transfer functions:

$$p_{kl}(x,y) = \cos^2\left(\frac{\pi}{3}\sqrt{(x-k)^2 + (y-l)^2}\right), \quad k-\frac{3}{2} \le x \le k+\frac{3}{2}, l-\frac{3}{2} \le y \le l+\frac{3}{2}$$

where k and l are the integer center points of the detectors. In fig. 8 the coverage area of each detector in the two-dimensional arrangement has been indicated by a circle. As in the one-dimensional case, a dot will activate only nearby detectors. The detectors activated by the dots at (1, 9) and (6.25, 2.75) have been indicated by thick solid circles.

Fig. 9 is a bar diagram illustrating the image percept vector generated by the detector arrangement in fig. 8. In fig. 9 the bars are distributed in a two-dimensional array similar to the coordinate grid in fig. 8. However, this array may be rearranged into a column vector, as in the one-dimensional case, by starting with column 1 in the array, concatenating column 2 to the end of column 1, concatenating column 3 to the end of column 2, etc. Another way of rearranging the array into a vector is to concatenate the rows of the array instead and then transpose the obtained row vector into a column vector. In fact, how the array is rearranged into a vector is irrelevant, for the purposes of the present invention, as long as all detector outputs are included in the resulting image percept vector $\mathbf{x}$ and they maintain the same position throughout all steps. The image percept vector components may simply be viewed as a collection of unordered channels (channel representation). In a typical system the image percept vector $\mathbf{x}$ has between 10^2 to 10^4 components.

The concept of percept vector may also be generalized to three-dimensional or four-dimensional (the fourth dimension representing time) images. The percept vector of such an image may still be formed by forming a column vector from the detector output signals.

The above described image percept vector $\mathbf{x}$ forms the basis for a feature vector $\mathbf{a}$, which is to be associated with a response state of the system. The feature vector $\mathbf{a}$ may include one or more of three different functions of the image percept vector, namely:

1.   Linear components, which are formed by the image percept vector

$$\mathbf{x} = \begin{pmatrix} x_1 \\ x_2 \\ \vdots \\ x_J \end{pmatrix}$$

5   itself or selected components thereof.

2.   Autocovariance products, which are formed by diagonal elements of the covariance product matrix

$$\mathbf{x}\mathbf{x}^T = \begin{pmatrix} x_1 x_1 & x_1 x_2 & \cdots & x_1 x_J \\ x_2 x_1 & x_2 x_2 & \cdots & x_2 x_J \\ \vdots & \vdots & \vdots & \vdots \\ x_J x_1 & x_J x_2 & \cdots & x_J x_J \end{pmatrix}$$

10   and are denoted $\mathbf{x}\mathbf{x}^T_{auto}$.

3.   Covariance products, which are formed by off-diagonal elements of the covariance product matrix $\mathbf{x}\mathbf{x}^T$, and are denoted $\mathbf{x}\mathbf{x}^T_{cov}$. Experiments in-
15   dicate that the covariance products are the most descriptive feature vector components, since they describe coincidences between events, but the other components should be kept in mind for various special purposes, such as improved redundancy, low feature density, etc.

20   Thus, a feature vector may have the form:

$$\mathbf{a} = \begin{pmatrix} \mathbf{x} \\ \mathbf{x}\mathbf{x}^T_{auto} \\ \mathbf{x}\mathbf{x}^T_{cov} \end{pmatrix} = \begin{pmatrix} a_1 \\ a_2 \\ \vdots \\ a_H \end{pmatrix}$$

In certain cases it may be desirable to employ a logarithmic representation of the feature vector **a**. Furthermore, if increased complexity is acceptable, it is also possible to include multi-covariant products (products of three or more percept vector components) in the feature vector.

In accordance with the present invention the feature vector **a** is used to generate a response vector **u** in accordance with the equation:

$$\mathbf{u} = \begin{pmatrix} u_1 \\ u_2 \\ \vdots \\ u_K \end{pmatrix} = \begin{pmatrix} c_{11} & c_{12} & \cdots & c_{1H} \\ c_{21} & c_{22} & \cdots & c_{2H} \\ \vdots & \vdots & \vdots & \vdots \\ c_{K1} & c_{K2} & \cdots & c_{KH} \end{pmatrix} \begin{pmatrix} a_1 \\ a_2 \\ \vdots \\ a_H \end{pmatrix} = \mathbf{Ca}$$

where **C** is denoted a linkage matrix, which will be described in further detail below. The response vector **u** may typically represent a characteristic of an object of interest, for example the horizontal or the vertical location of the center of a circle in an image, the diameter of a circle, the length of a straight line segment, the orientation of a line segment, etc. Note that the dimensionality H of the feature vector **a** may be (and typically is) different from the dimensionality K of the response vector **u**. Thus, in general the linkage matrix **C** is non-square.

The purpose of the linkage matrix **C** is to transform the generally continuous but spread out feature vector **a** into a likewise continuous but concentrated response vector **u**. To illustrate this statement, consider a circle of a certain diameter. This circle will result in a certain percept vector **x** and a corresponding feature vector **a**. The feature vector **a** will typically have bursts of non-zero elements separated by regions of zero elements. The linkage matrix **C** acts as a "concentrator" that transforms the feature vector **a** into a response vector **u** having a single burst of non-zero elements. If the diameter of the circle is changed slightly, the corresponding feature vector **a** will be different, since the bursts will be redistributed, while the response vector **u** will only shift its single burst slightly. What is essential here is the local continuity

between variation of the output of a particular active channel and the variation of the property and/or the position of the object having the property sensed by the channel. Continuous change of a response variable locally will correspond to local, continuous changes within a group of feature channels. A particular combination of active feature channels and their values will correspond to a particular, unique response state (response vector). The major characteristic of this system is that it is locally continuous at the same time as it allows global discontinuity. The system is continuous and linear in its local mapping of the feature vector over the linkage matrix. On the other hand, it is highly non-linear and discontinuous in its global mapping, in the sense that features come and go, and there is no requirement that feature channels are adjacent in some space. As noted above, there is no requirement that the channels are located next to each other in the percept vector, as "they will find each other" with a properly optimized linkage matrix (this procedure is described below). Thus, the illustrations presented in this specification, with active channels next to each other, is only for visualization purposes, to make the description more comprehensible. In fact, the channels may be arranged at random, as long as the arrangement is fixed over the entire process and every channel reacts continuously to stimuli.

Once the response vector has been obtained in channel representation form, it may be desirable, especially for technical systems, to obtain a scalar value representing the response. This scalar value may, for example, be used to specify the location of an object, to drive a motor or to visualize system states on a screen.

The output from a single channel u_k of a response vector $\mathbf{u}$, will not provide an unambiguous representation of the corresponding scalar signal u, as there will be an ambiguity in terms of the position of u with respect to the center of the activated channel. This ambiguity may, however, be resolved by the combination of adjacent channel responses within the response vector $\mathbf{u} = \{u_k\}$. By using a sufficiently dense representation in terms of channels, it is possible

to employ the knowledge of a particular distance between different channel contributions (detectors). An example of a suitable algorithm will now be given.

If the distance in phase between adjacent raised cosine detectors is $\pi/3$ or less, an approximate reconstruction of u from the response vector **u** is possible. As noted above, the response vector **u** will have a burst with only a few non-zero values. A first approximation of u may be obtained by the average:

$$\bar{I} = \frac{\sum_{k=1}^{K} k \cdot u_k}{\sum_{k=1}^{K} u_k}$$

This average is a coarse measure of the location of the burst. A refined estimate û of u may be obtained in accordance with:

$$\begin{cases} \hat{u} = I + \delta \\ I = floor(\bar{I}) \end{cases}$$

where *floor* is a function that sets its argument to the nearest integer that is less than or equal to the argument, and δ is a correction defined by:

$$\delta = 2 \cdot atan2(x, y) / \pi$$

where atan2 is the four-quadrant inverse tangent function defined in the interval $[-\pi, \pi]$ (as defined in MATLAB®, for example), and x, y are defined by:

$$\begin{cases} x = u_I - u_{I+2} & u_j = 0 \quad if \ j > K \\ y = u_{I+1} - u_{I-1} & u_j = 0 \quad if \ j < 1 \end{cases}$$

From the above description it is clear that it is the relation between two or more channels that allows a continuous mapping between a channel representation and a conventional scalar representation.

The linkage matrix $\mathbf{C}$ is determined by a training procedure, which will now be described with reference to fig. 10.

Fig. 10 is a diagram of a circle that is shifted along a horizontal line. Each position of the circle results in a different pair of feature vector $\mathbf{a}^i$ and response vector $\mathbf{u}^i$. However, each pair should be linked by the same linkage matrix $\mathbf{C}$. This leads to the following set of equations:

$$\mathbf{U} = \begin{pmatrix} u_1^1 & u_1^2 & \cdots & u_1^N \\ u_2^1 & u_2^2 & \cdots & u_2^N \\ \vdots & \vdots & \vdots & \vdots \\ u_K^1 & u_K^2 & \cdots & u_K^N \end{pmatrix} = \begin{pmatrix} c_{11} & c_{12} & \cdots & c_{1H} \\ c_{21} & c_{22} & \cdots & c_{2H} \\ \vdots & \vdots & \vdots & \vdots \\ c_{K1} & c_{K2} & \cdots & c_{KH} \end{pmatrix} \begin{pmatrix} a_1^1 & a_1^2 & \cdots & a_1^N \\ a_2^1 & a_2^2 & \cdots & a_2^N \\ \vdots & \vdots & \vdots & \vdots \\ a_H^1 & a_H^2 & \cdots & a_H^N \end{pmatrix} = \mathbf{CA}$$

where N denotes the number of shift positions or the length of the training sequence and $\mathbf{A}$ is denoted a feature matrix. These equations may be solved by conventional approximate methods (typically methods that minimize mean squared errors) to determine the linkage matrix $\mathbf{C}$ (see [1]). With respect to this minimization the continuity in each channel is crucial, because this is what makes it possible to perform an optimization. Once the linkage matrix $\mathbf{C}$ has been determined, an arbitrary circle position along the horizontal line may be detected from its feature vector $\mathbf{a}$ to produce the corresponding response vector $\mathbf{u}$.

Fig. 11 is a diagram of a circle that is shifted along a vertical line. These shifted circles may in a similar way be used to find a linkage matrix $\mathbf{C}^v$ linking a feature vector $\mathbf{a}$ to a response vector $\mathbf{v}$ representing vertical position along a vertical line. Note that the linkage matrix $\mathbf{C}^v$ corresponding to vertical position is in general different from the previous linkage matrix $\mathbf{C}$ (or rather $\mathbf{C}^u$ since it is associated with $\mathbf{u}$) corresponding to horizontal position.

The previous paragraphs demonstrated how linkage matrices could be determined for finding circle positions along either a horizontal or a vertical

line. However, usually it would be desirable to find the position of an object in a xy-plane. In a first approximation this can be accomplished by treating the horizontal and vertical directions as independent of each other, and by assuming that the linkage matrix for one coordinate direction is independent of the other coordinate. Thus, the linkage matrix $\mathbf{C}^u$ obtained from fig. 10 is assumed to be determined from training on horizontal lines at many y-positions over the entire image and consequently valid for each horizontal line, while the linkage matrix $\mathbf{C}^v$ obtained from fig. 11 is assumed to be similarly determined from training on vertical lines at many x-positions over the entire image and consequently valid for each vertical line. In practice, training data for estimation of both matrices will be obtained during the same session, where x and y are in some regular or arbitrary pattern made to assume values within the area of definition. With these assumptions the position of a circle in the xy-plane may be expressed (in channel representation) as:

$$\begin{cases} \mathbf{u} = \mathbf{C}^u \mathbf{a} \\ \mathbf{v} = \mathbf{C}^v \mathbf{a} \end{cases}$$

This algorithm works remarkably well in spite of its simplicity. The reason for this is that different sets of features generally are active in different regions or intervals of u and v.

A more accurate algorithm is given by the following coupled equations:

$$\begin{cases} \mathbf{u} = \mathbf{C}^u \mathbf{v} \otimes \mathbf{a} = \mathbf{C}^u \mathbf{a}^u \\ \mathbf{v} = \mathbf{C}^v \mathbf{u} \otimes \mathbf{a} = \mathbf{C}^v \mathbf{a}^v \end{cases}$$

where $\otimes$ denotes the Kronecker product. For example:

$$a^u = v \otimes a = \begin{pmatrix} v_1 a \\ v_2 a \\ \vdots \\ v_L a \end{pmatrix} = \begin{pmatrix} v_1 a_1 \\ v_1 a_2 \\ \vdots \\ v_1 a_H \\ v_2 a_1 \\ v_2 a_2 \\ \vdots \\ v_2 a_H \\ \vdots \\ v_L a_1 \\ v_L a_2 \\ \vdots \\ v_L a_H \end{pmatrix}$$

where L is the dimensionality of $\mathbf{v}$. It is noted that in these coupled equations the coupled feature vectors $\mathbf{a}^u$ and $\mathbf{a}^v$ are of higher dimensionality than the uncoupled feature vector $\mathbf{a}$. This also leads to correspondingly larger linkage matrices $\mathbf{C}^u$ and $\mathbf{C}^v$. These coupled equations may be solved by conventional iterative methods. For example, they may be expressed as:

$$\begin{cases} \mathbf{u}(i) = \mathbf{C}^u \mathbf{v}(i-1) \otimes \mathbf{a} \\ \mathbf{v}(i) = \mathbf{C}^v \mathbf{u}(i-1) \otimes \mathbf{a} \end{cases}$$

where index i is an iteration index. This iterated sequence typically converges in a few iteration steps.

The training procedure is similar to the uncoupled case, except that coupled feature matrices $\mathbf{A}^u$ and $\mathbf{A}^v$ defined by:

$$\mathbf{A}^u = \begin{pmatrix} v_1^1\mathbf{a}^1 & v_1^2\mathbf{a}^2 & \cdots & v_1^N\mathbf{a}N \\ v_2^1\mathbf{a}^1 & v_2^2\mathbf{a}^2 & \cdots & v_2^N\mathbf{a}^N \\ \vdots & \vdots & \vdots & \vdots \\ v_L^1\mathbf{a}^1 & v_L^2\mathbf{a}^2 & \cdots & v_L^N\mathbf{a}^N \end{pmatrix} \qquad \mathbf{A}^v = \begin{pmatrix} u_1^1\mathbf{a}^1 & u_1^2\mathbf{a}^2 & \cdots & u_1^N\mathbf{a}^N \\ u_2^1\mathbf{a}^1 & u_2^2\mathbf{a}^2 & \cdots & u_2^N\mathbf{a}^N \\ \vdots & \vdots & \vdots & \vdots \\ u_K^1\mathbf{a}^1 & u_K^2\mathbf{a}^2 & \cdots & u_K^N\mathbf{a}^N \end{pmatrix}$$

are used instead of the uncoupled feature matrix **A**. Here the superscripts refer to the respective training samples. It is noted that **u** and **v** may have different dimensionalities K and L, respectively.

From the description above it is clear that the coupled model is more complex than the uncoupled model. However, it is also more accurate, since the added complexity gives a richer model with larger linkage matrices.

For a circle another feature, namely the size of the circle may be of interest. This feature may be extracted from the same feature vector **a** as the location by using another linkage matrix **C^w**. Thus, if the size (the radius or diameter) of the circle is represented by the response vector **w**, one obtains:

$$\mathbf{w} = \mathbf{C}^w\mathbf{a}$$

Fig. 12 is a diagram of a set of different size circles that may be used for training purposes if the simple uncoupled model is used. This model will give satisfactory results as long as the center of the circle to be detected is near the training position. Combined with the previously described uncoupled model for the circle position, it is now possible to completely describe a circle having arbitrary position and size by the set of equations:

$$\begin{cases} \mathbf{u} = \mathbf{C}^u\mathbf{a} \\ \mathbf{v} = \mathbf{C}^v\mathbf{a} \\ \mathbf{w} = \mathbf{C}^w\mathbf{a} \end{cases}$$

This requires that the **C** matrices are trained over the entire combined defini-tion range of the scalars u, v and w that correspond to response vectors **u**, **v** and **w**.

A more accurate model is a coupled model that considers variations in both circle position and size. This model is described by the equations:

$$
\left\{
\begin{array}{l}
\mathbf{u} = \mathbf{C}^u \begin{pmatrix} \mathbf{v} \\ \mathbf{w} \end{pmatrix} \otimes \mathbf{a} = \mathbf{C}^u \mathbf{a}^u \\[3mm]
\mathbf{v} = \mathbf{C}^v \begin{pmatrix} \mathbf{u} \\ \mathbf{w} \end{pmatrix} \otimes \mathbf{a} = \mathbf{C}^v \mathbf{a}^v \\[3mm]
\mathbf{w} = \mathbf{C}^w \begin{pmatrix} \mathbf{u} \\ \mathbf{v} \end{pmatrix} \otimes \mathbf{a} = \mathbf{C}^w \mathbf{a}^w
\end{array}
\right.
$$

In these equations the vectors within parenthesis are obtained by concate-nating the indicated vectors. Thus, a coupled feature vector such as $\mathbf{a}^u$ may explicitly be written:

$$
\mathbf{a}^u = \begin{pmatrix} v_1 \mathbf{a} \\ v_2 \mathbf{a} \\ \vdots \\ v_L \mathbf{a} \\ w_1 \mathbf{a} \\ w_2 \mathbf{a} \\ \vdots \\ w_M \mathbf{a} \end{pmatrix}
$$

where L and M denote the dimensionality of **v** and **w**, respectively. This also implies that the **C** matrices are larger than in the uncoupled case. As previ-ously these coupled equations may be solved by iterative methods.

The coupled feature matrices used for training are obtained in a similar way. For example, the coupled feature matrix $\mathbf{A}^u$ may be expressed as:

$$
\mathbf{A}^u = \begin{pmatrix}
v_1^1 \mathbf{a}^1 & v_1^2 \mathbf{a}^2 & \cdots & v_{1\;1}^N \mathbf{a}^N \\
v_2^1 \mathbf{a}^1 & v_2^2 \mathbf{a}^2 & \cdots & v_2^N \mathbf{a}^N \\
\vdots & \vdots & \vdots & \vdots \\
v_L^1 \mathbf{a}^1 & v_L^2 \mathbf{a}^2 & \cdots & v_L^N \mathbf{a}^N \\
w_1^1 \mathbf{a}^1 & w_1^2 \mathbf{a}^2 & \cdots & w_1^N \mathbf{a}^N \\
w_2^1 \mathbf{a}^1 & w_2^2 \mathbf{a}^2 & \cdots & w_2^N \mathbf{a}^N \\
\vdots & \vdots & \vdots & \vdots \\
w_M^1 \mathbf{a}^1 & w_M^2 \mathbf{a}^2 & \cdots & w_M^N \mathbf{a}^N
\end{pmatrix}
$$

The coupled model may be generalized to any number of response vectors required to describe an object. The general rule for forming coupled feature vectors is to concatenate all response vectors except the one for which a coupled feature vector is sought. The sought feature vector is then formed by the outer or Kronecker product between the concatenated vector and the uncoupled feature vector.

A variation of this coupled model (in the multi-dimensional case) is to refrain from concatenation of vectors and instead apply the Kronecker product operator several times. Thus, in the three-dimensional case one obtains:

$$
\begin{cases}
\mathbf{u} = \mathbf{C}^u \mathbf{w} \otimes \mathbf{v} \otimes \mathbf{a} = \mathbf{C}^u \mathbf{a}^u \\
\mathbf{v} = \mathbf{C}^v \mathbf{u} \otimes \mathbf{w} \otimes \mathbf{a} = \mathbf{C}^v \mathbf{a}^v \\
\mathbf{w} = \mathbf{C}^w \mathbf{v} \otimes \mathbf{u} \otimes \mathbf{a} = \mathbf{C}^w \mathbf{a}^w
\end{cases}
$$

A coupled feature vector such as $\mathbf{a}^u$ may explicitly be written as:

$$\mathbf{a}^u = \begin{pmatrix} w_1 v_1 \mathbf{a} \\ w_1 v_2 \mathbf{a} \\ \vdots \\ w_1 v_L \mathbf{a} \\ w_2 v_1 \mathbf{a} \\ w_2 v_2 \mathbf{a} \\ \vdots \\ w_2 v_L \mathbf{a} \\ \vdots \\ w_M v_1 \mathbf{a} \\ w_M v_2 \mathbf{a} \\ \vdots \\ w_M v_L \mathbf{a} \end{pmatrix}$$

The coupled model described above couples vectors on the input side. However, it is also possible to employ a coupled model that uses coupled response vectors instead. For two response vectors **u** and **v** this model may be expressed by the equation:

$$\mathbf{u} \otimes \mathbf{v} = \mathbf{C}^{uv}\mathbf{a}$$

where $\mathbf{u} \otimes \mathbf{v}$ denotes the Kronecker product of **u** and **v**:

$$\mathbf{u} \otimes \mathbf{v} = \begin{pmatrix} u_1 \mathbf{v} \\ u_2 \mathbf{v} \\ \vdots \\ u_K \mathbf{v} \end{pmatrix} = \begin{pmatrix} u_1 v_1 \\ u_1 v_2 \\ \vdots \\ u_1 v_L \\ u_2 v_1 \\ u_2 v_2 \\ \vdots \\ u_2 v_L \\ \vdots \\ u_K v_1 \\ u_K v_2 \\ \vdots \\ u_K v_L \end{pmatrix}$$

and **a** is the corresponding feature vector. The linkage matrix $\mathbf{C}^{uv}$ is estimated by a training procedure as in the previously described models. This training procedure results in the set of equations:

$$\left((\mathbf{u} \otimes \mathbf{v})^1 \quad (\mathbf{u} \otimes \mathbf{v})^2 \quad \dots \quad (\mathbf{u} \otimes \mathbf{v})^N \right) = \mathbf{C}^{uv} \mathbf{A}$$

where N denotes the number of samples in the training set. This response vector coupled model gives more localized responses, as compared to the other models, which is an advantage if the feature vectors for a particular problem are not well localized.

Once the linkage matrix $\mathbf{C}^{uv}$ has been determined from the training procedure, it is possible to uncouple the coupled response vector $\mathbf{u} \otimes \mathbf{v}$ to obtain estimates of the individual vectors **u** and **v**. Such estimates may be obtained from the following set of equations:

$$\begin{cases} \hat{u}_k = d \sum_{l=1}^{L} u_k v_l & k = 1, \ldots, K \\ \hat{v}_l = d \sum_{k=1}^{K} u_k v_l & l = 1, \ldots, L \end{cases}$$

where d is a scale factor due to the summation of components scaled by the sum of the other response vector. In the case discussed above, with raised cosine transfer functions and a channel separation of $\pi/3$, the sum of a fully activated channel vector is always 1.5, and the scale factor then becomes $d=1/1.5$. Furthermore, in these equations only the products $u_k v_l$ and not the individual factors u_k and v_l are assumed to be known.

In three dimensions this model may be generalized to:

$$\begin{cases} \mathbf{u} \otimes \mathbf{v} = \mathbf{C}^{uv} \mathbf{a} \\ \mathbf{u} \otimes \mathbf{w} = \mathbf{C}^{uw} \mathbf{a} \\ \mathbf{v} \otimes \mathbf{w} = \mathbf{C}^{vw} \mathbf{a} \end{cases}$$

After training and determination of the linkage matrices, estimates of the uncoupled response vectors $\mathbf{u}$, $\mathbf{v}$ and $\mathbf{w}$ may be obtained from the coupled response vectors. However, since each coupled response vector determines two uncoupled response vector estimates, there will now be two estimates for each uncoupled response vector $\mathbf{u}$, $\mathbf{v}$ and $\mathbf{w}$. These two estimates may be compared to each other, in order to provide a more redundant and reliable estimate of the response vector.

Another embodiment of this model reduces this redundancy by coupling only exclusive pairs of response vectors. In such a model response vectors $\mathbf{u}$, $\mathbf{v}$, $\mathbf{w}$ and $\mathbf{t}$ are coupled in accordance with:

$$\begin{cases} \mathbf{u} \otimes \mathbf{v} = \mathbf{C}^{uv} \mathbf{a} \\ \mathbf{w} \otimes \mathbf{t} = \mathbf{C}^{wt} \mathbf{a} \end{cases}$$

The solution of these equations gives single estimates of each response vector. Such a single non-redundant estimate is deemed sufficient for most cases. In the case of further response vectors, additional coupled pairs may be introduced as required.

The above described model with coupled output vectors may also be represented in outer product notation instead of Kronecker product notation. In this notation the model becomes:

$$
\mathbf{uv}^T = \begin{pmatrix} u_1 v_1 & u_1 v_2 & \cdots & u_1 v_L \\ u_2 v_1 & u_2 v_2 & \cdots & u_2 v_L \\ \vdots & \vdots & \vdots & \vdots \\ u_K v_1 & u_K v_2 & \cdots & u_K v_L \end{pmatrix} = \mathbf{D}^{uv}\mathbf{a}
$$

where $\mathbf{D}^{uv}$ denotes a three-dimensional matrix having the same elements as $\mathbf{C}^{uv}$, but arranged in a three-dimensional array instead of a two-dimensional array. It is also noted that $\mathbf{uv}^T$ contains exactly the same elements as $\mathbf{u} \otimes \mathbf{v}$, but that the elements are arranged as a two-dimensional array (matrix) instead of a one-dimensional array (vector). Thus, the two notations are mathematically equivalent. The matrix $\mathbf{D}^{uv}$ is obtained by a training procedure that results in the set of equations:

$$
\mathbf{UV} = \left(\left(\mathbf{uv}^T\right)^1 \ \left(\mathbf{uv}^T\right)^2 \ \cdots \ \left(\mathbf{uv}^T\right)^N \right) = \mathbf{D}^{uv}\left(\mathbf{a}^1 \ \mathbf{a}^2 \ \cdots \ \mathbf{a}^N \right) = \mathbf{D}^{uv}\mathbf{A}
$$

Here **UV** represents a three-dimensional matrix rather than the product of two matrices **U** and **V**.

Still another coupled model may be obtained by coupling response vectors to linkage matrices. This model may be seen as a variation of the just discussed model. This variation consists of projecting the matrix **uv** on the vector **v**, such that:

$$\mathbf{u}\mathbf{v}^T v = \mathbf{u}|v|^2$$

which gives $\mathbf{u}$ except for a scale factor $|v|^2$, which may be normalized.

If the same projection is performed on the right hand side ($\mathbf{D}^{uv}\mathbf{a}$), one may define (in component notation) the projected matrix $\mathbf{C}^u$:

$$c_{kh}^u = s_{kh}^u \sum_{l=1}^{L} v_l d_{klh}^{uv}$$

where s_{kh}^u are scale factors. After performing such projections this model may be expressed as (in two dimensions):

$$\begin{cases} \mathbf{u} = \mathbf{C}^u \mathbf{a} \\ \mathbf{v} = \mathbf{C}^v \mathbf{a} \end{cases}$$

Since the three-dimensional linkage matrix $\mathbf{D}^{uv}$ (on which $\mathbf{C}^u$ and $\mathbf{C}^v$ are based) is the same as in the previously discussed model, the same training procedure may be used.

Generalization to more than 2 response vectors is similar to previously discussed models. For example, with three response vectors one obtains:

$$\begin{cases} \mathbf{u} = \mathbf{C}^u \mathbf{a} \\ \mathbf{v} = \mathbf{C}^v \mathbf{a} \\ \mathbf{w} = \mathbf{C}^w \mathbf{a} \end{cases}$$

Here the coupled linkage matrices are defined by:

$$\begin{cases} c_{kh}^{u} = s_{kh}^{u} \sum_{i=1}^{L+M} \alpha_i d_{kih}^{u(vw)} \\ c_{lh}^{v} = s_{lh}^{v} \sum_{i=1}^{M+K} \beta_i d_{lih}^{v(wu)} \\ c_{mh}^{w} = s_{mh}^{w} \sum_{i=1}^{K+L} \gamma_i d_{mih}^{w(uv)} \end{cases} \qquad \begin{cases} h = 1 \ldots H \\ k = 1 \ldots K \\ l = 1 \ldots L \\ m = 1 \ldots M \end{cases}$$

where the coupling vectors α, β, γ are defined as:

$$\alpha = \begin{pmatrix} v \\ w \end{pmatrix} \qquad \beta = \begin{pmatrix} w \\ u \end{pmatrix} \qquad \gamma = \begin{pmatrix} u \\ v \end{pmatrix}$$

and

$$\left\{ d_{kih}^{u(vw)} \right\} = \mathbf{D}^{u(vw)} \qquad \left\{ d_{lih}^{v(wu)} \right\} = \mathbf{D}^{v(wu)} \qquad \left\{ d_{mih}^{w(uv)} \right\} = \mathbf{D}^{w(uv)}$$

define the three (three-dimensional) linkage matrices.

A linkage matrix typically has the following properties:

1. The elements of the linkage matrix are preferably non-negative, as this gives a more sparse matrix and a more stable system. Negative values are, however, allowed in principle.

2. The elements of the linkage matrix are preferably limited in magnitude, as this as well gives a more stable system.

3. The linkage matrix is sparse (has few non-zero elements). This implies that the system may be handled by procedures that are optimized for solving sparse systems of equations (see [2]) for values between two limits (see [3]), for example 0 and 1.

4.   An even sparser linkage matrix providing more efficient computation, essentially without affecting performance, may be obtained by discarding matrix elements below a predefined threshold (for example 0.01 if the elements are allowed to vary between 0 and 1). The same method may also be applied to feature matrix **A**.

In the description above the present invention has been described with reference to a specific type of object, namely a circle. However the same principles may be applied to other types of objects as well. For example, fig. 13 is a diagram illustrating a detector arrangement for detecting line segments ([4] describes line detection in general). An essential aspect of a line segment is its orientation. The detectors in fig. 13 will detect both position and orientation. Such a detector may have a composite transfer function described by:

$$p_{klm}(x,y,\phi) = \cos^2\left(\frac{\pi}{3}\sqrt{(x-k)^2 + (y-l)^2}\right)\cos^2\left(\phi + m\frac{\pi}{4}\right), \quad \begin{cases} k - \dfrac{3}{2} \le x \le k + \dfrac{3}{2} \\ l - \dfrac{3}{2} \le y \le l + \dfrac{3}{2} \\ m = 0,1,2,3, \\ \left|\phi + m\dfrac{\pi}{4}\right| \le \dfrac{\pi}{2} \end{cases}$$

Thus, there are four detector types (corresponding to m=0,1,2,3), each detector type having a specific preferred orientation. In order to detect an arbitrary orientation of a line segment, these four detector types have to be distributed over the detection region, for example as in fig. 13. The distribution may be systematic, as in fig 13, or random. Typically these detectors are less densely arranged than the previously discussed position detectors, due to the fact that the expected object, a line, will activate several detectors. As previously the outputs from the detectors are arranged in a percept vector, from which a feature vector is formed. A trained linkage matrix is used to obtain a response vector representing the line orientation in channel representation form. If desired this response vector may be converted into a scalar orientation value.

Other characteristics for a line segment are its position and length. These properties may be detected from the same feature vector as the orientation by using different trained linkage matrices. As previously it is possible to use both a coupled and an uncoupled model. Training of the linkage matrices is performed by using different line segments having different known positions, lengths and orientations.

Other objects, such as triangles, squares, arcs, ellipses etc may be detected in similar ways.

Another essential feature of the method in accordance with the present invention is that a response vector may be used as a percept vector for detection of higher level characteristics. Thus, it is possible to detect a composite object by combining response vectors from its parts into a new percept vector, form a new feature vector representing the composite object and form new response vectors representing the composite object with new trained linkage matrices.

Fig. 14 is an embodiment of an artificial vision system in accordance with the present invention. An external world scene 10, real or simulated, is recorded by a geometric mapper 12, such as a camera, a video camera or any other means that produces one or several images to be analyzed. A receptor to channel mapper 14 including an array of detectors produces a percept vector for each image. A computational structure 16, typically including a microprocessor or a micro/signal processor combination, transforms each percept vector into a corresponding feature vector and generates response vectors describing an object by using corresponding trained linkage matrices. Computational structure 16 is also connected to a training sequencer 18, During a training phase this training sequencer generates changes, either systematic or pseudo random, in the external world. For example, the position and/or size of an object that the system is intended to track is changed (the size of the object in a two-dimensional image may, for example, represent the distance to the object). Training sequencer 18 provides each position with coordinate

values and each size with a size value. These coordinate and size values are transformed to channel representation in a response to channel mapper 20. Similarly, the obtained sequence of response vectors is recorded in computational structure 16 and associated with corresponding detected feature vectors. When the training sequence is complete, a control signal from training sequencer 18 informs computational structure 16 that the training sequence has been completed. Computational structure 16 then finds the linkage matrices to be used in the future for detecting the same type of object.

Fig. 15 is a flow chart illustrating an embodiment of the method in accordance with the present invention. After training the linkage matrices in step S1, step S2 gets an image to analyze. Step S3 generates the percept vector from the image. Step S4 transforms this percept vector into a set of coupled feature vectors. Step S5 generates a corresponding set of response vectors. Step S6 uses these response vectors for further processing. This further processing may include forming new feature vectors for higher level processing or converting response vectors to scalars for controlling the real word system represented by the image. Finally the method gets the next image and repeats the process.

It will be understood by those skilled in the art that various modifications and changes may be made to the present invention without departure from the scope thereof, which is defined by the appended claims.

REFERENCES

[1]   Using MATLAB, MathWorks Inc, 1996, pp. 4-2 – 4-3, 4-13 – 4-14

[2]   Using MATLAB, MathWorks Inc, 1996, pp. 9-2 – 9-4, 4-33 – 4-36

[3]   MATLAB Reference Guide, MathWorks Inc, 1992, pp. 341 - 342

[4]   B. Jähne, "Practical Handbook on Image Processing for Scientific Applications", CRC Press, 1997, pp. 416-440.

CLAIMS

1. An artificial vision method, **characterized** by:

    generating an image percept vector;

    transforming said image percept vector into a feature vector; and

    generating a response array by multiplying said feature vector by a trained linkage matrix modeling a percept-response system.

2. The method of claim 1, **characterized** by said feature vector including the covariance products of said image percept vector.

3. The method of claim 2, **characterized** by said feature vector including the auto-covariance products of said image percept vector.

4. The method of claim 3, **characterized** by said feature vector including components of said image percept vector.

5. The method of any of the preceding claims, **characterized** in that the elements of said linkage matrix are non-negative.

6. The method of claim 5, **characterized** in that the elements of said linkage matrix are restricted to values between zero and a predetermined positive value.

7. The method of any of the preceding claims, **characterized** by forming a coupled feature vector by coupling said feature vector to a response array, represented by a vector, using a Kronecker product before performing said matrix multiplication.

8. The method of any of the preceding claims, **characterized** by forming a coupled feature vector by coupling said feature vector to several response arrays, represented by vectors, using repeated Kronecker products before performing said matrix multiplication.

9. The method of any of the preceding claims 1-6, **characterized** by said response array being a coupled response vector formed by two response vectors coupled to each other by a Kronecker product.

10. The method of any of the preceding claims 1-6, **characterized** by said response array being a coupled response matrix formed by two response vectors coupled to each other by an outer product.

11. The method of any of the preceding claims 1-6, **characterized** by said linkage matrix being a coupled linkage matrix formed by weighting a set of uncoupled linkage matrices with the elements of another response vector.

12. The method of any of the preceding claims, **characterized** by converting each response vector into a corresponding scalar response signal.

13. The method of any of the preceding claims, **characterized** by discarding linkage matrix elements below a predefined threshold.

14. The method of any of the preceding claims, **characterized** by said percept vector being sparse, each non-zero percept vector element giving a continuous representation limited in definition range with respect to some variable property of an object in an image.

15. The method of any of the preceding claims, **characterized** by said percept vector being sparse, each non-zero percept vector element giving a continuous representation, limited in spatial range, of the position an object in an image.

16. An artificial vision system, **characterized** by:

  means (12, 14) for generating an image percept vector;

  means (16) for transforming said image percept vector into a feature vector; and

means (16) for generating a response array by multiplying said feature vector by a trained linkage matrix modeling a percept-response system.

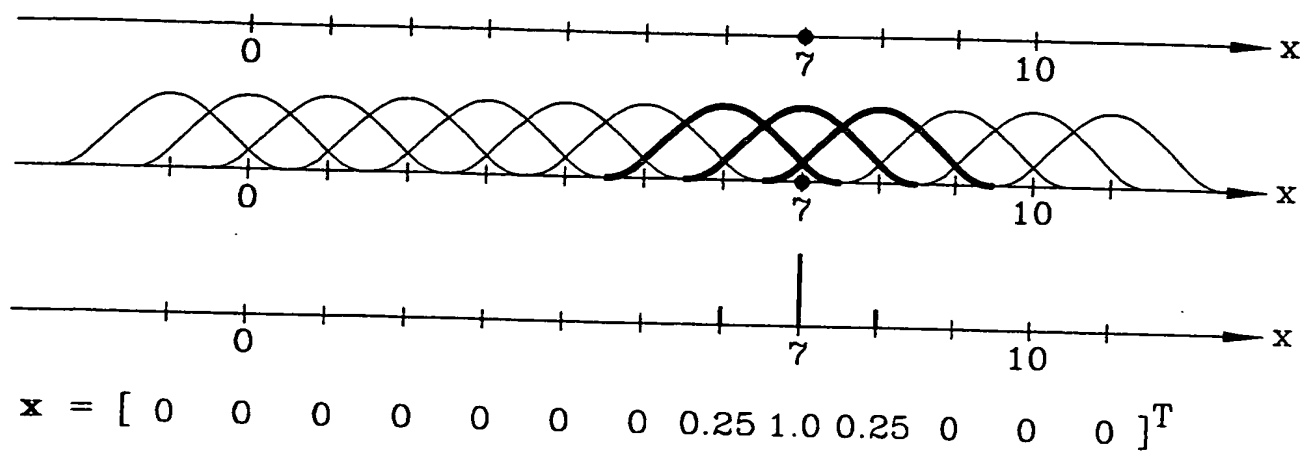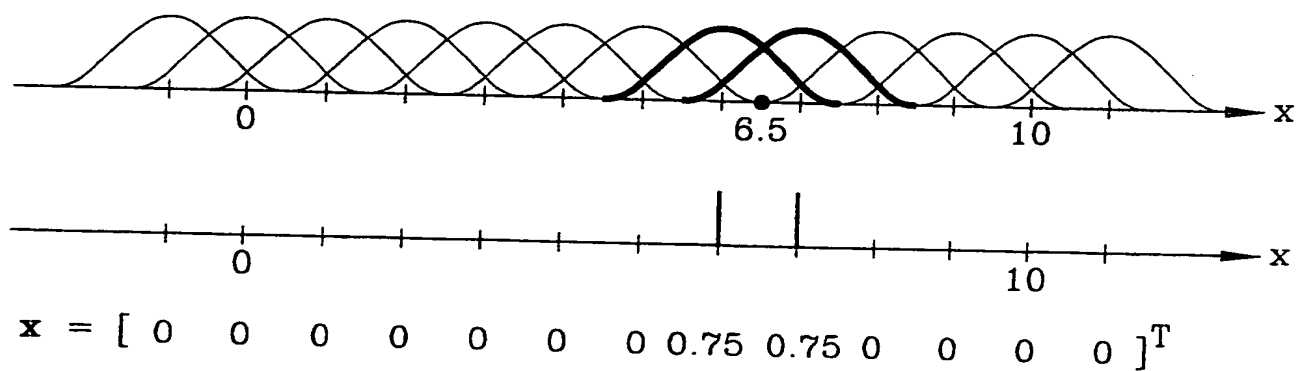17. The system of claim 16, **characterized** by means (18, 20) for training said linkage matrix.

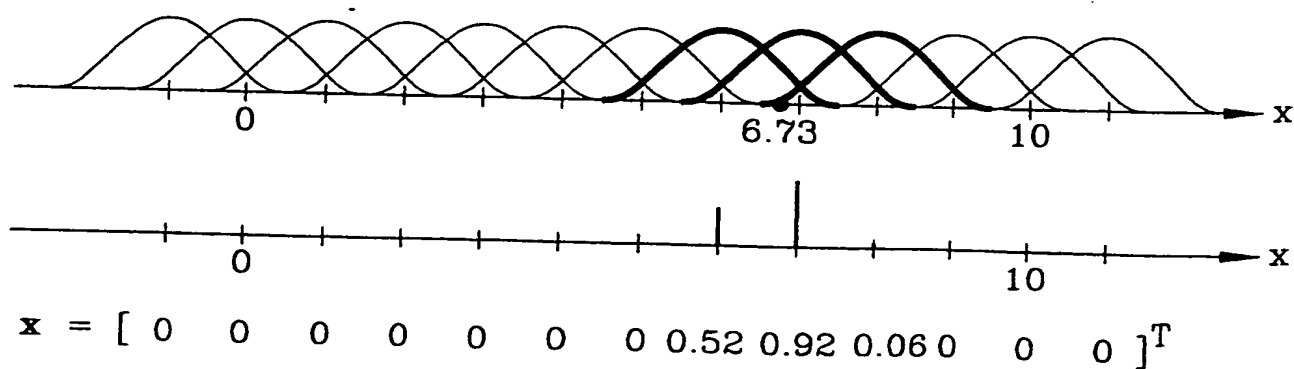18. A percept-response system for sensing and control, **characterized** by:

means (12, 14) for generating a percept vector;

means (16) for transforming said percept vector into a feature vector; and

means (16) for generating a response array by multiplying said feature vector by a trained linkage matrix modeling said percept-response system.

19. The system of claim 18, **characterized** by means (18, 20) for training said linkage matrix.
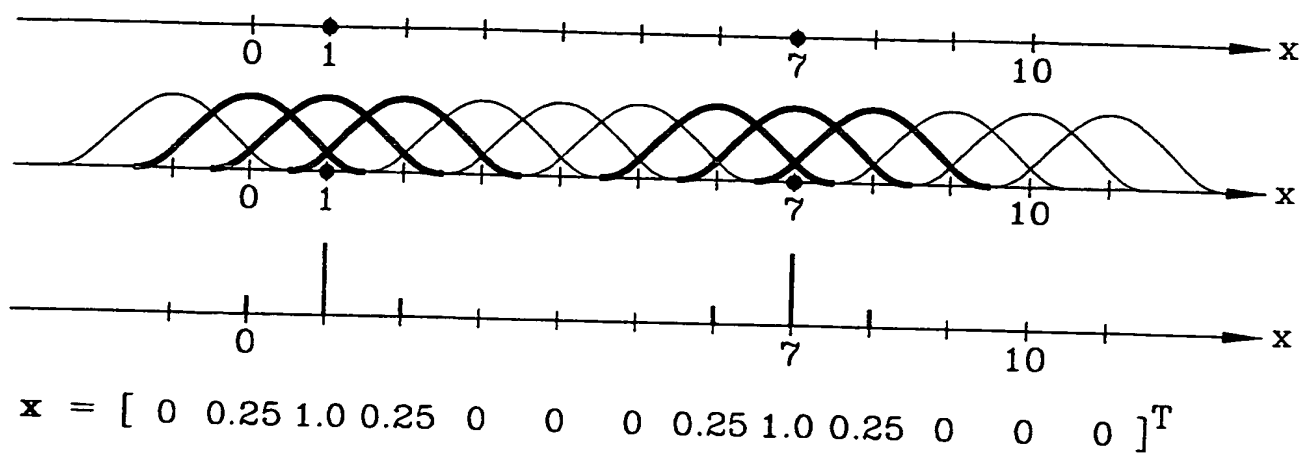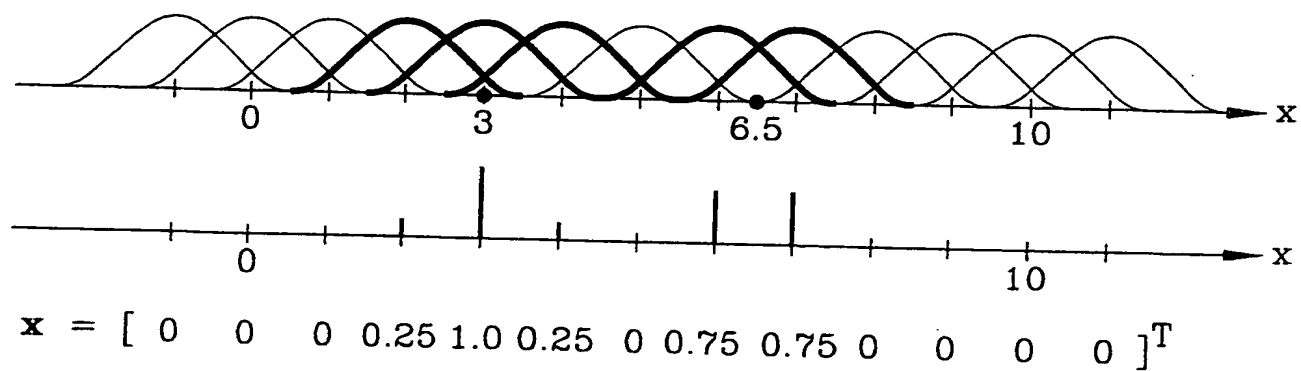
$$\mathbf{x} = [\ 0\quad 0\quad 0\quad 0\quad 0\quad 0\quad 0\quad 0.25\ 1.0\ 0.25\quad 0\quad 0\quad 0\ ]^T$$

Fig. 1

$$\mathbf{x} = [\ 0\quad 0\quad 0\quad 0\quad 0\quad 0\quad 0\ 0.75\ 0.75\ 0\quad 0\quad 0\quad 0\ ]^T$$

Fig. 2

$$\mathbf{x} = [\ 0\quad 0\quad 0\quad 0\quad 0\quad 0\quad 0\ 0.52\ 0.92\ 0.06\ 0\quad 0\quad 0\ ]^T$$

Fig. 3

$x = [\ 0 \ \ 0.25 \ 1.0 \ 0.25 \ \ 0 \ \ \ \ 0 \ \ \ \ 0 \ \ 0.25 \ 1.0 \ 0.25 \ \ 0 \ \ \ \ 0 \ \ \ \ 0 \ ]^T$

Fig. 4

$x = [\ 0 \ \ \ \ 0 \ \ \ \ 0 \ \ 0.25 \ 1.0 \ 0.25 \ \ 0 \ 0.75 \ 0.75 \ 0 \ \ \ \ 0 \ \ \ \ 0 \ \ \ \ 0 \ ]^T$

Fig. 5

$x = [\ 0 \ \ \ \ 0 \ \ \ \ 0 \ \ \ \ 0 \ \ \ \ 0 \ 0.25 \ 1.0 \ 0.77 \ 0.92 \ 0.06 \ 0 \ \ \ \ 0 \ \ \ \ 0 \ ]^T$

Fig. 6

Fig. 7

Fig. 8

Fig. 9

Fig. 10

Fig. 11

Fig. 12

Fig. 13

Fig. 14

11/11

TRAIN LINKAGE
MATRICES — S1

GET NEXT
IMAGE — S2

GENERATE
PERCEPT VECTOR — S3

GENERATE COUPLED
FEATURE VECTORS — S4

GENERATE
RESPONSE VECTORS — S5

PROCESS
RESPONSE VECTORS — S6
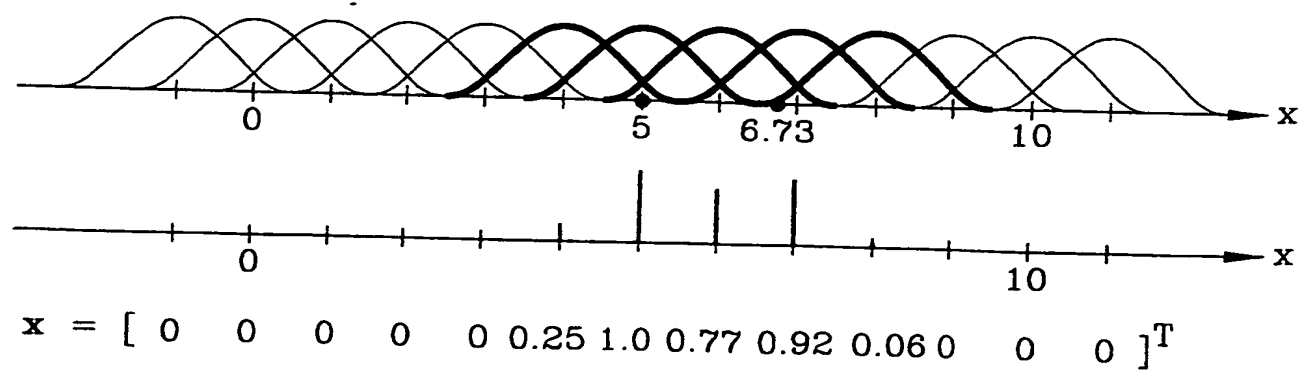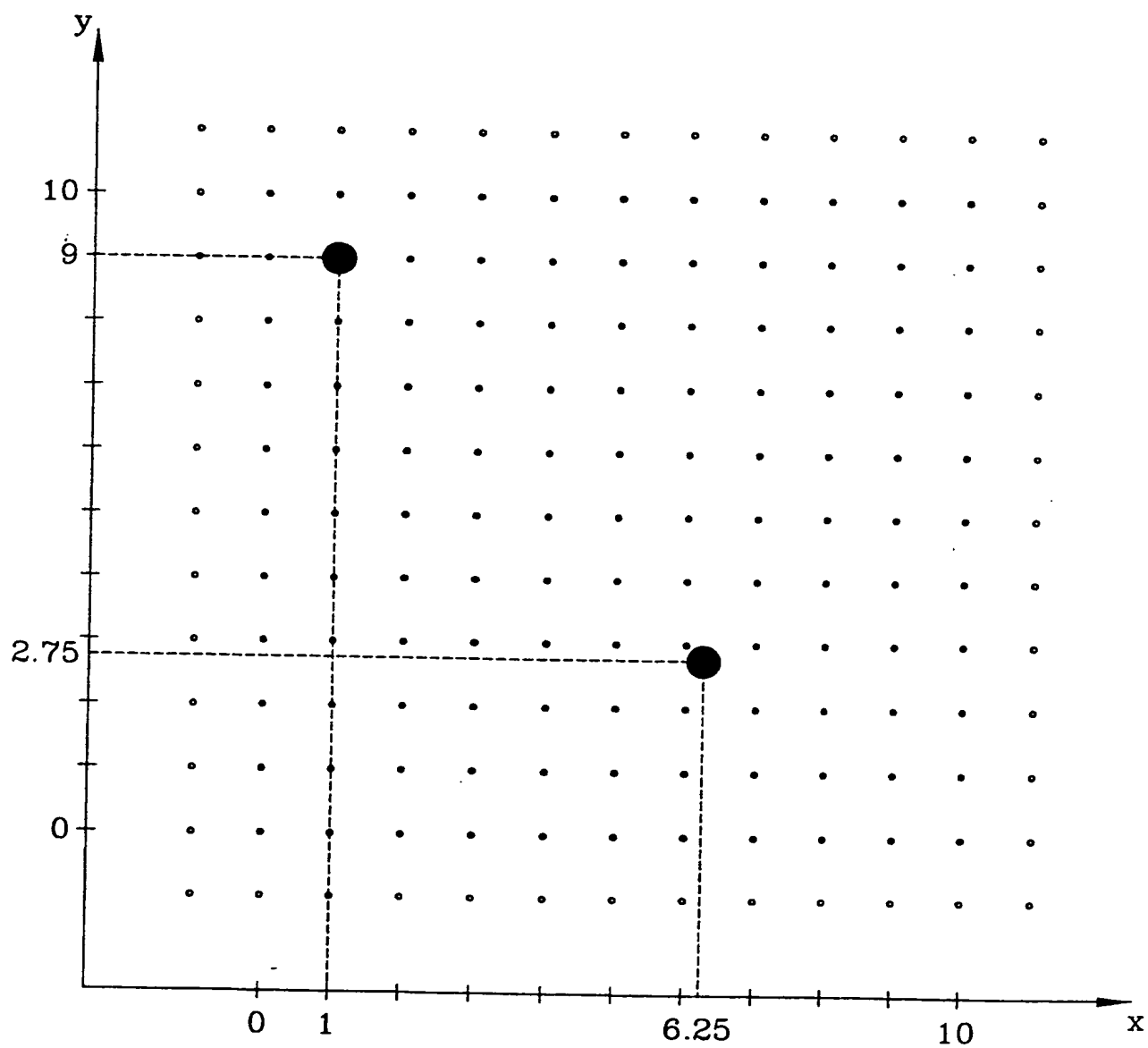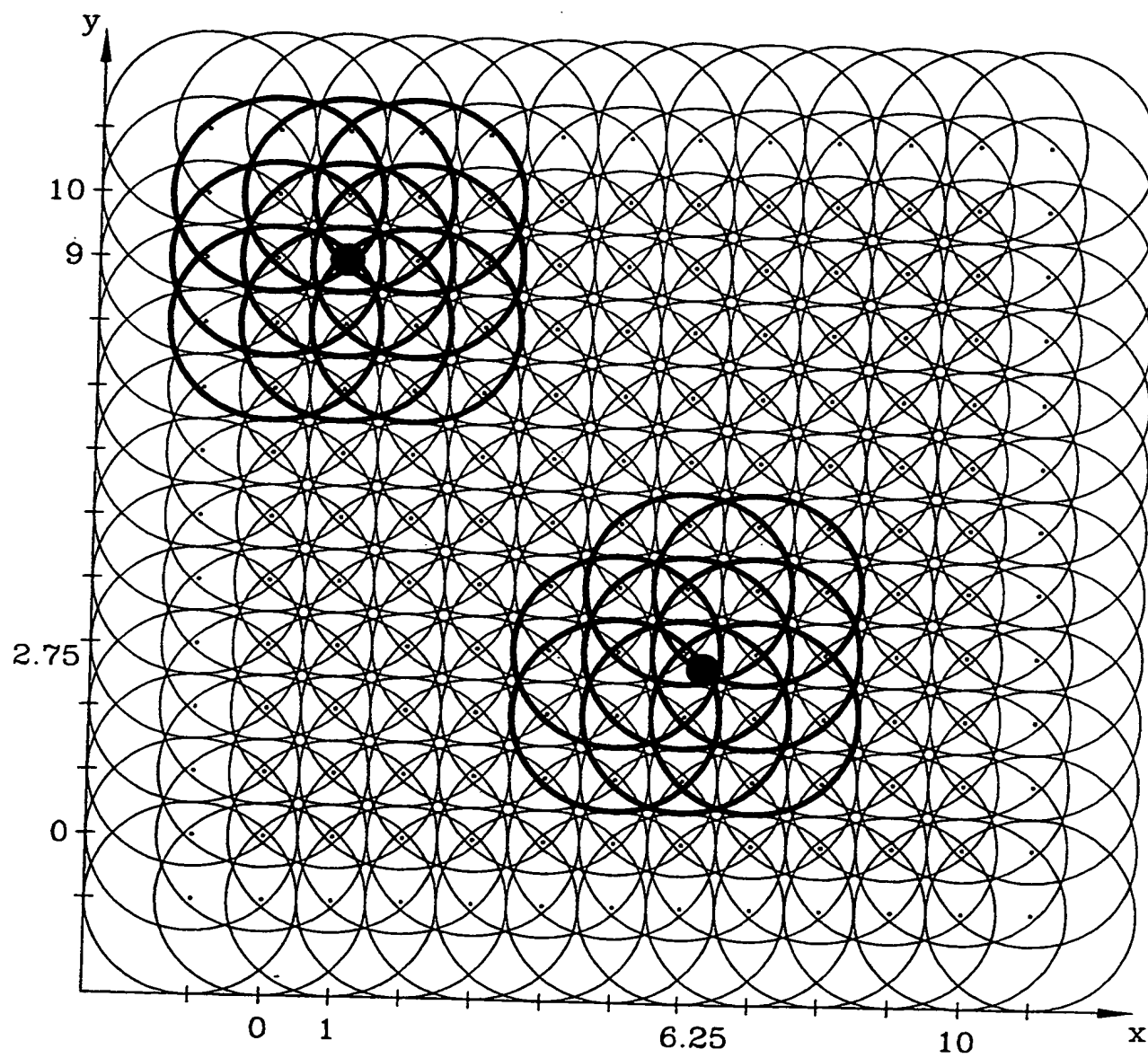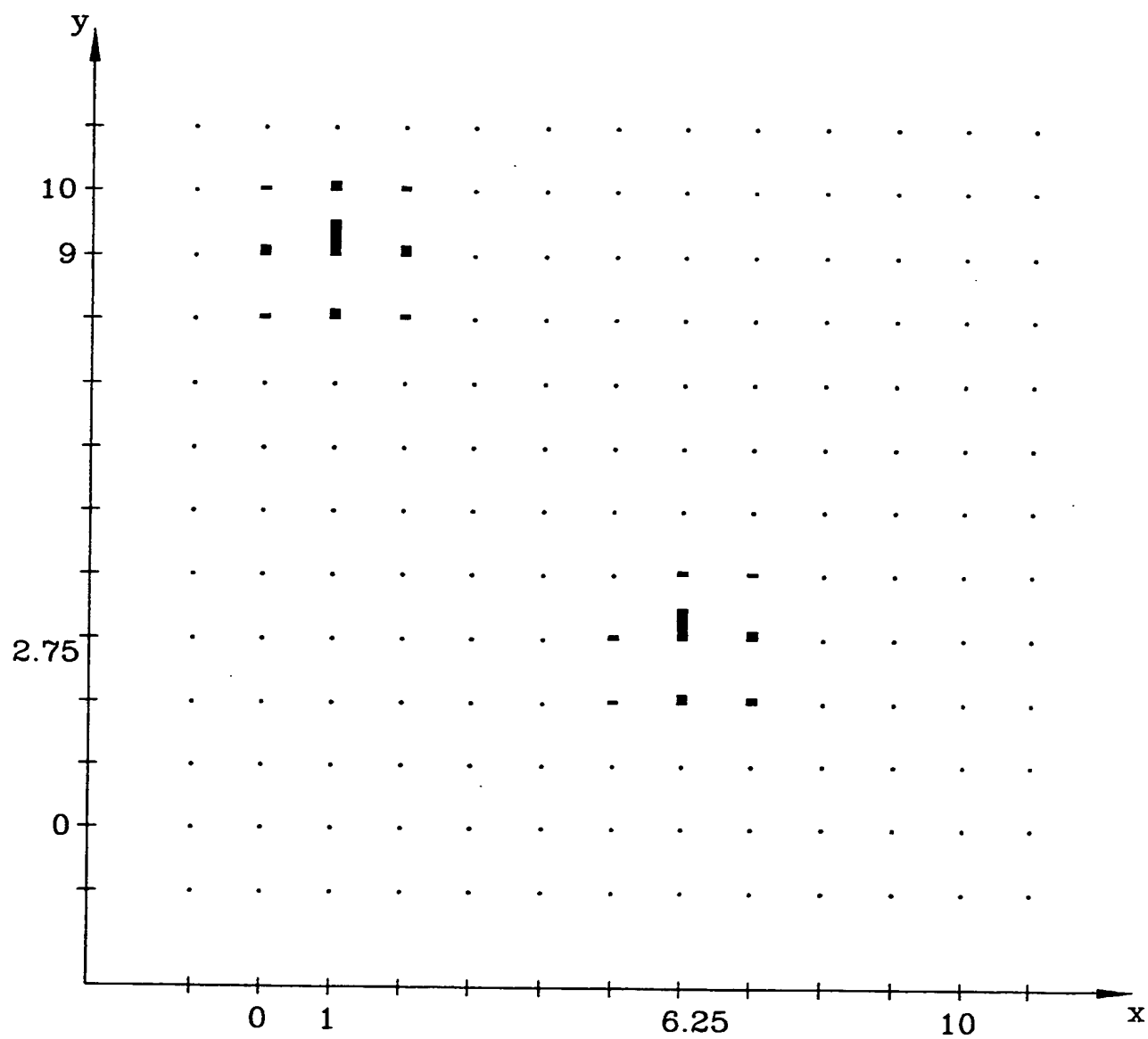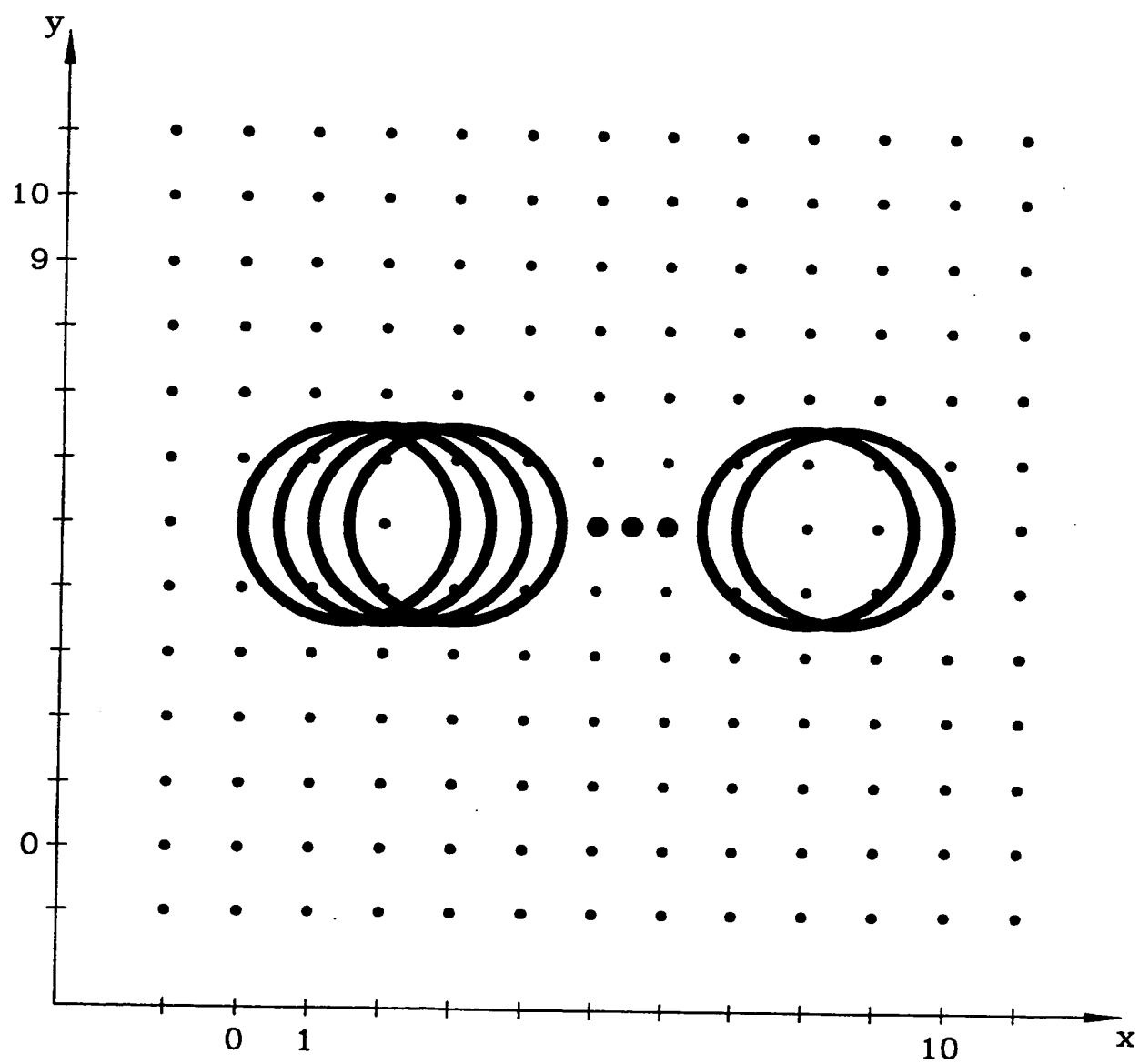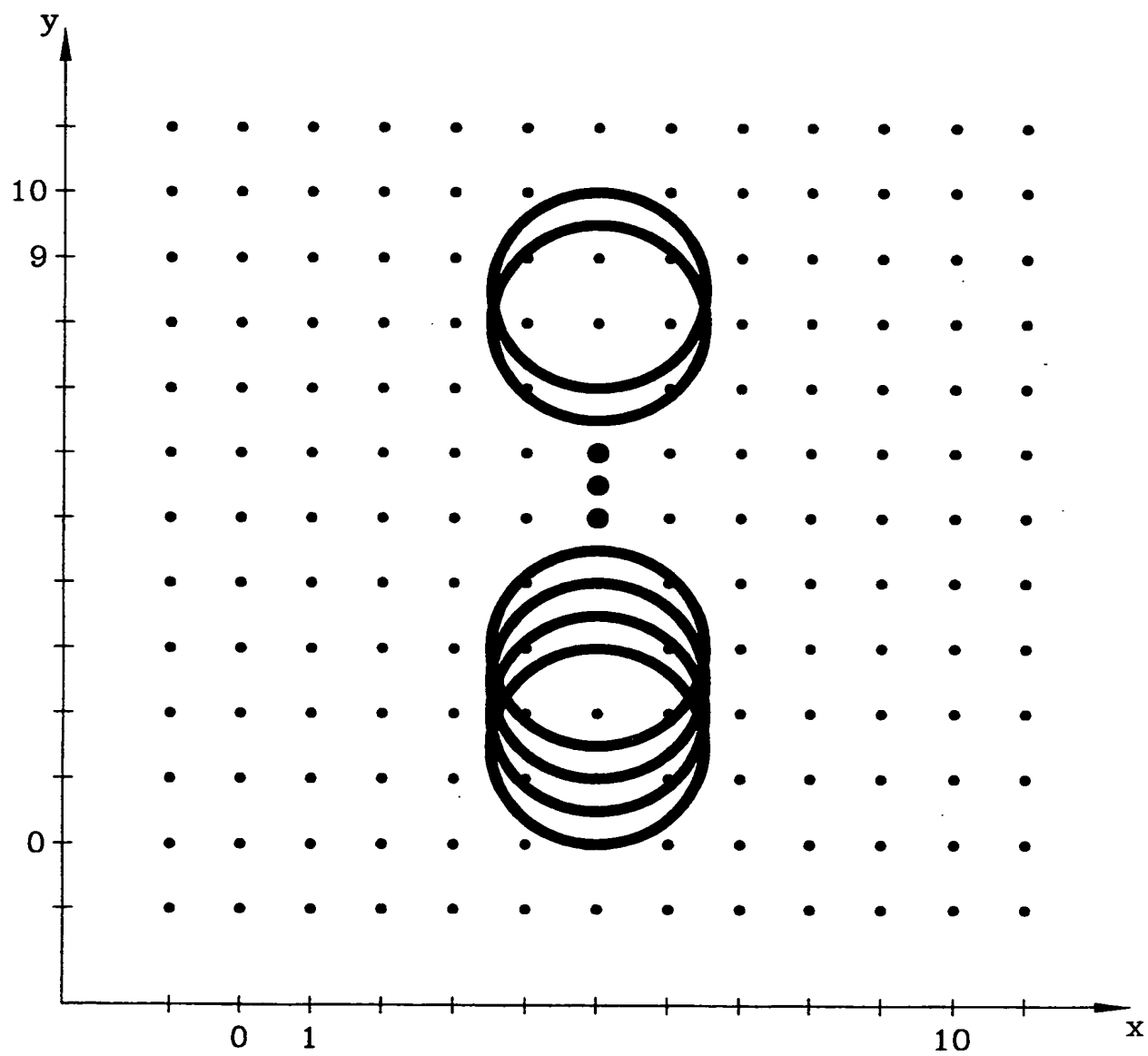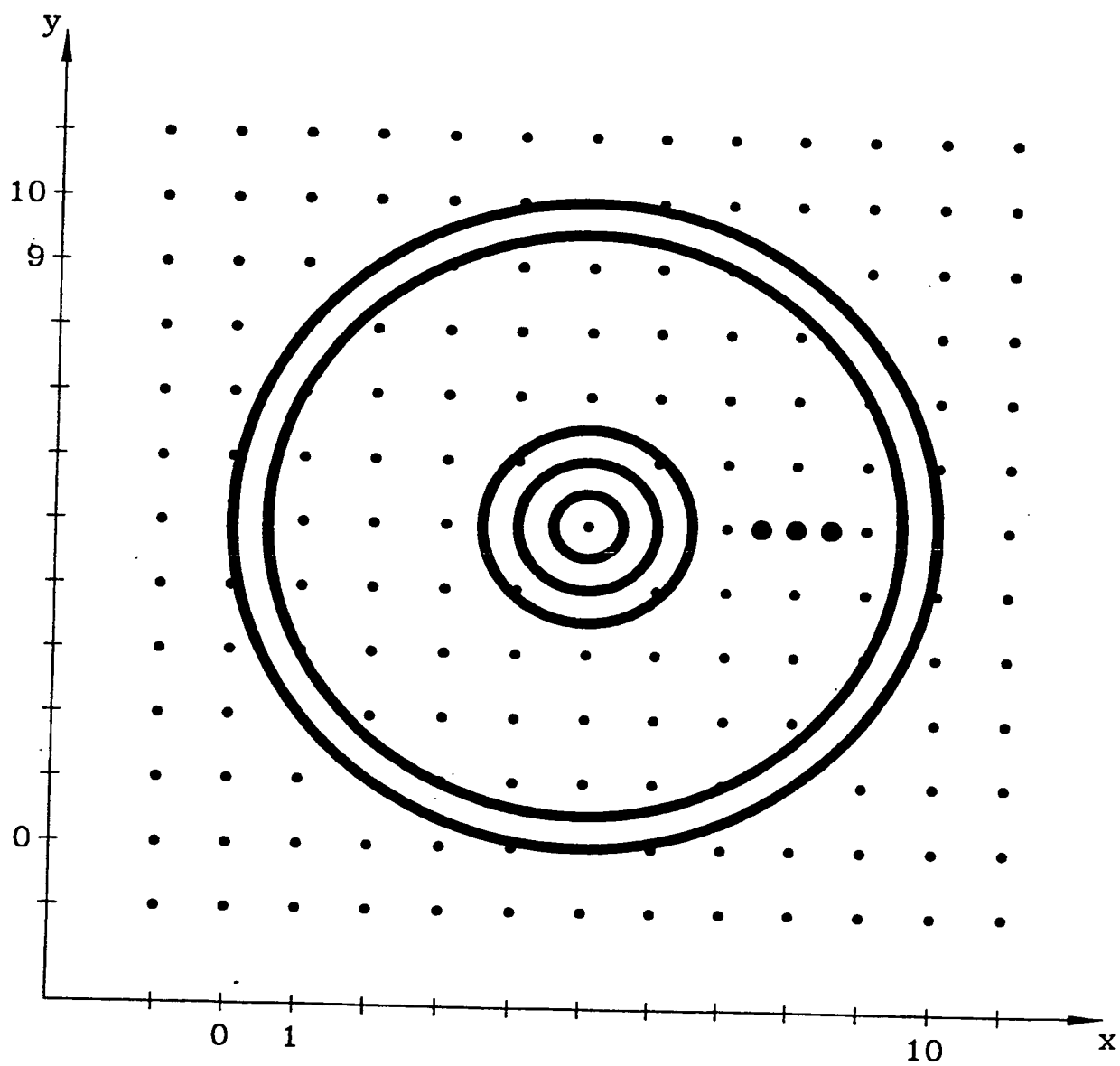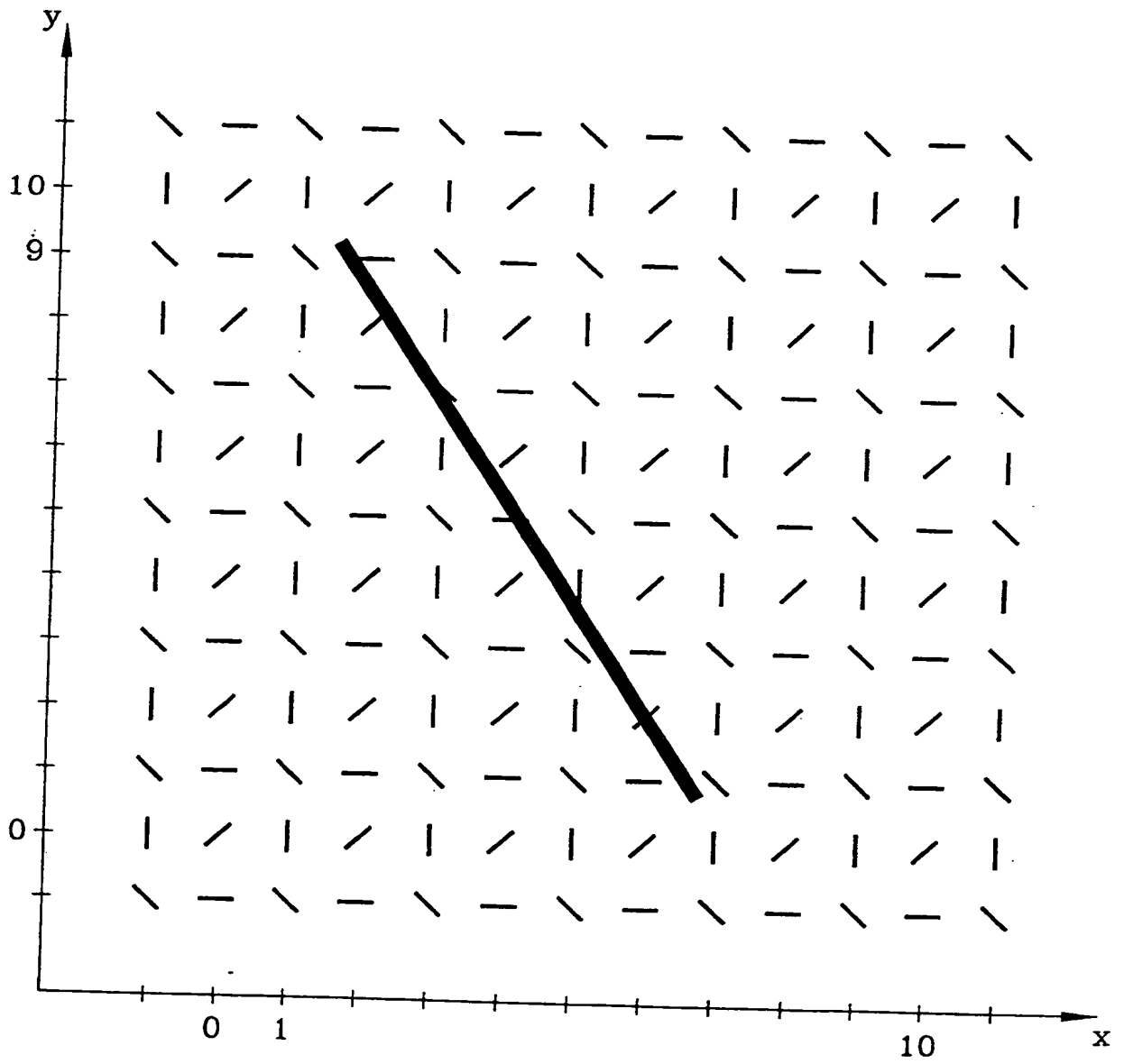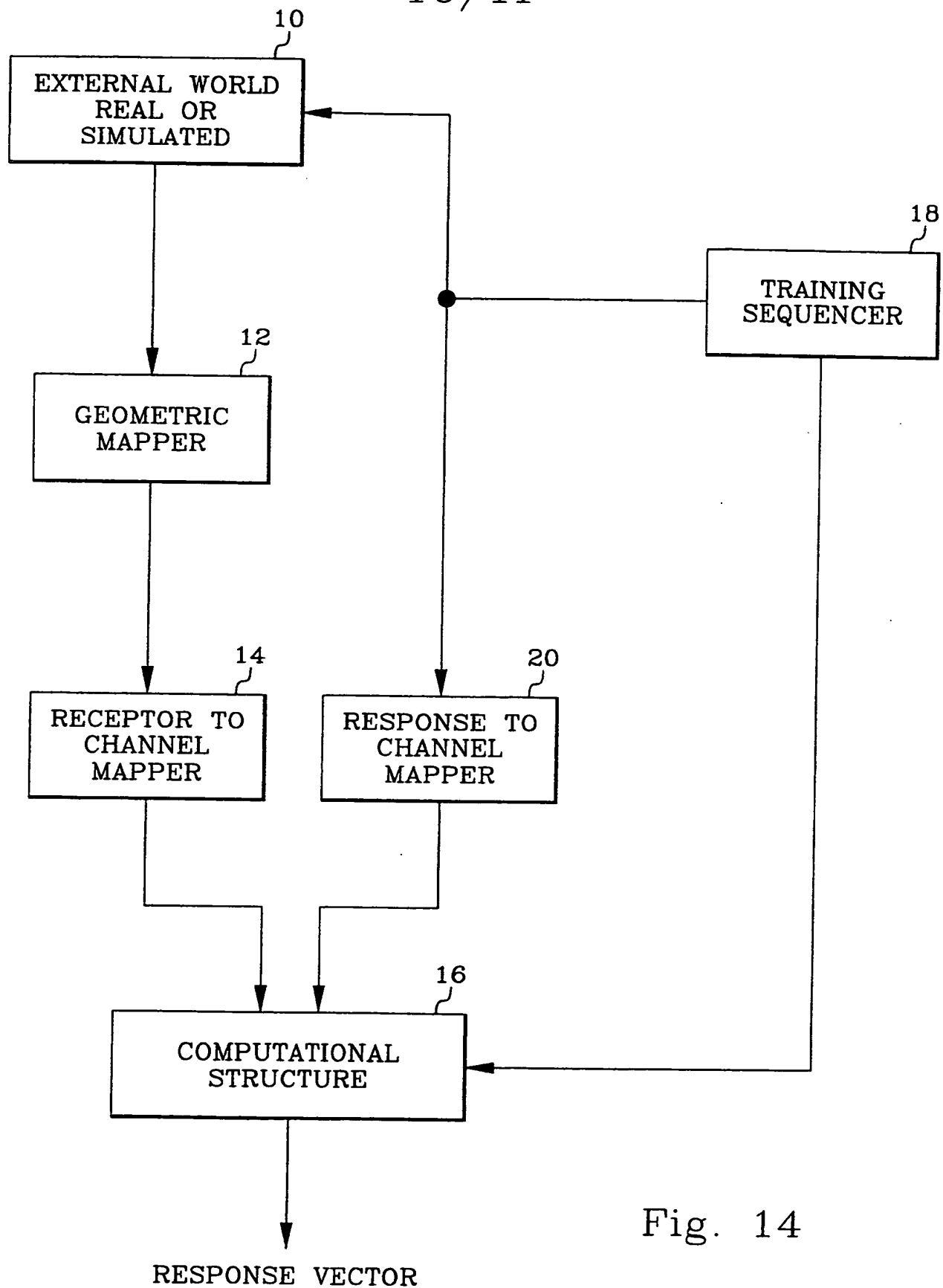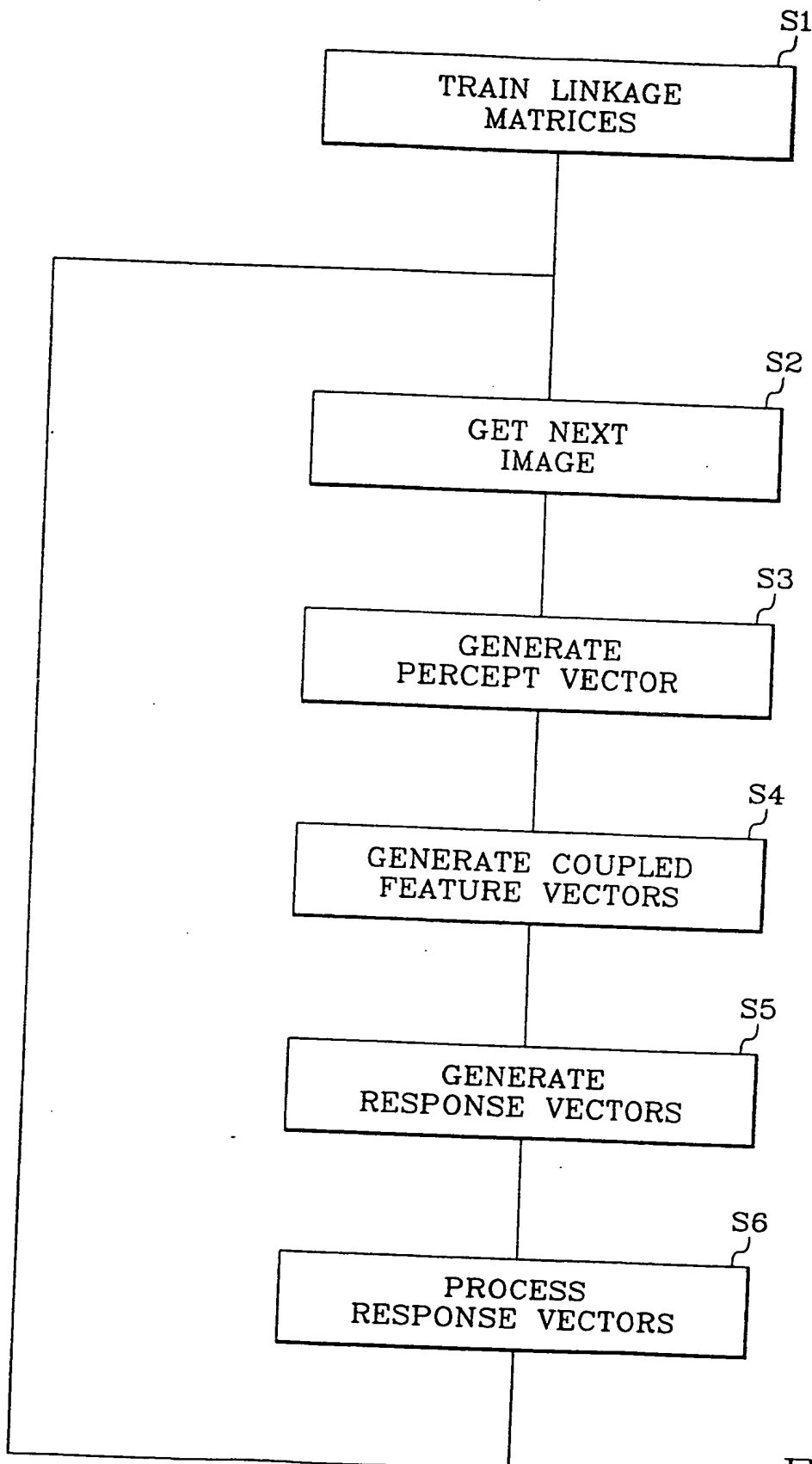
Fig. 15

INTERNATIONAL SEARCH REPORT

A. CLASSIFICATION OF SUBJECT MATTER

IPC7: G06T 9/00, G06T 7/00, G06K 9/00
According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

IPC7: G06K, G06T, G06F

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

SE,DK,FI,NO classes as above

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US 5301019 A (R.W. CITTA), 5 April 1994 (05.04.94), figure 2, abstract	1-15,16-17, 18-19
E,A	WO 9930270 A1 (INTEL CORPORATION), 17 June 1999 (17.06.99), figure 4, abstract	1-15,16-17, 18-19

☐ Further documents are listed in the continuation of Box C.   ☒ See patent family annex.

* Special categories of cited documents:	"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
"A" document defining the general state of the art which is not considered to be of particular relevance	
"E" erlier document but published on or after the international filing date	"X" document of particular relevance: the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)	"Y" document of particular relevance: the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art
"O" document referring to an oral disclosure, use, exhibition or other means	
"P" document published prior to the international filing date but later than the priority date claimed	"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
17 February 2000	24 -02- 2000
Name and mailing address of the ISA/	Authorized officer
Swedish Patent Office	
Box 5055, S-102 42 STOCKHOLM	Patrik Blidefalk/AE
Facsimile No. + 46 8 666 02 86	Telephone No. + 46 8 782 25 00

INTERNATIONAL SEARCH REPORT

Information on patent family members

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
US 5301019 A	05/04/94	NONE	
WO 9930270 A1	17/06/99	AU 1412199 A	28/06/99